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New data on the stratigraphy of the folded Miocene Zone at the front of the Ukrainian Outer Carpathians

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ABSTRACT:

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The litho- and biostratigraphy (calcareous nannofossils and foraminifera) were studied in several sections of the folded Miocene Zone (Boryslav–Pokuttya and Sambir nappes) of the Ukrainian Outer Carpathians. Based on new biostratigraphic data, the age and correlation of the folded Miocene deposits in the marginal part of the Ukrainian and Polish Outer Carpathians were established. The deposits studied range from the Early Miocene (Early Burdigalian NN2 Zone) to the early Late Miocene (NN9 Zone). The facies and similarity in ages of the youngest deposits of the folded Middle Miocene strata in Poland [Stebnik (Sambir) Nappe and Zgłobice thrust-sheets] and in Ukraine (Sambir Nappe) implies that they were folded at same time and that they represent a similar system of tectonic units, developed in front of the advancing Carpathian orogen.

Key words: Lithostratigraphy, Biostratigraphy, Calcareous nannoplankton, Miocene, Boryslav–Pokuttya and Sambir Nappes, Outer Carpathians, Ukraine.

INTRODUCTION

In Ukraine and Poland along the front of the Outer Carpathians there is a wide zone of folded Miocene deposits. In Ukraine, these deposits belong to the Boryslav–Pokuttya and Sambir nappes, whereas in Poland they are known as the Stebnik Nappe and Zgłobice thrust sheets. The continuation of the Boryslav–Pokuttya Nappe into the Polish Carpathians is still under discussion. The Stebnik Nappe in Poland is equivalent to the Sambir Nappe in Ukraine, while the equivalents of the Zgłobice thrust-sheets have not been established in the Ukrainian Carpathians.

This paper provides the litho- and biostratigraphic framework for the folded Miocene deposits in Ukraine, and its correlation with the equivalent succession in Poland. The age of folded Miocene deposits plays an important role in understanding of the palaeogeography and tectonics of the Outer Carpathians and its foreland.

This project, undertaken jointly by the Institute of Geological Sciences at the Jagiellonian University in Kraków, the Institute of Geological Sciences NAS

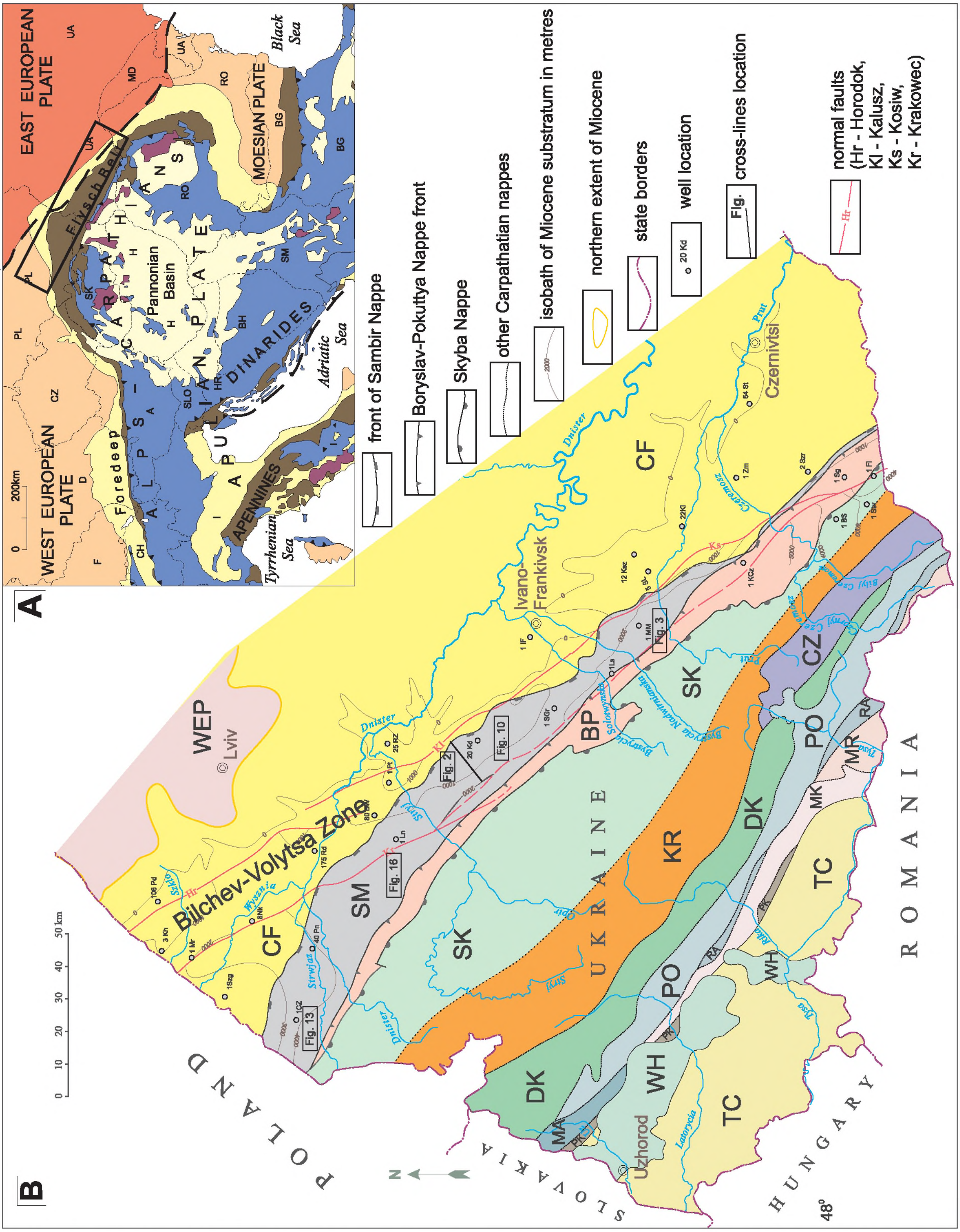

Fig. 1. A – Position of the study area in the Alpine–Carpathian system (after PICHA 1996, modified by OSZCZYPKO & *al*. 2006); B – Tectonic map of the Ukrainian Carpathians (after ŚLĄCZKA & *al*. 2006, simplified). Abrevations: WEP – West European Platform, CF – Carpathian Foredeep, SM – Sambir Nappe, BP – Boryslav–Pokuttya Nappe, SK – Skyba/Skole Nappe, KR – Krosno Zone, DK – Dukla Nappe, CZ – Chornohora Nappe, PO – Porkulec Nappe, RA – Rakhiv Nappe, MR – Marmarosh Massif, Marmarosh Klippen Zone, Ma – Magura Nappe, PKB – Pieniny Klippen Belt, WH – Vihorlat–Gutin Volcanic Massif, TC – Trans-Carpathian Depression

Ukraine in Kyiv and the Ukrainian State Geological Research Institute in Lviv, started in 2001. Some of the earlier results were published by ANDREYEVA-GRIGOROVICH & *al.* (2003).

GEOLOGICAL SETTING

The marginal part of the Ukrainian Carpathians (the Krosno, Skyba and Boryslav–Pokuttya nappes) is composed mainly of flysch deposits of Cretaceous to Early Miocene age. The Middle Miocene (Badenian and Sarmatian) strata occur as a post-tectonic sedimentary cover that overlies the marginal part of the folded Carpathians Skyba Nappe. In the folded Miocene Zone molasse deposits are known from the Sambir Nappe succession (Text-figs 1, 2). However, some authors (BUROV & *al.* 1978; SMIRNOV & *al.* 2000) regard the Boryslav–Pokuttya and Sambir nappes as tectonic units derived from the internal part of the foredeep. The autochthonous Bilche-Volytsya Zone that rests directly on the platform basement (ANDREYEVA-GRIGOROVICH & *al.* 2003; OSZCZYPKO & *al.* 2006) is represented by sediments of Middle and Late Miocene age. A characteristic feature of both the Sambir and Bilche–Volytsya zones is the Late Badenian evaporite horizon.

LITHOSTRATIGRAPHY

Skyba Nappe

The Skyba Nappe consists of several thrust-sheets (skybas) which are overthrust on the foreland for a distance of tens of kilometres (BUROV & *al.* 1978; ŚLĄCZKA & *al.* 2006). Towards the south-west this nappe dips under the Krosno Nappe (Text-fig. 1B).

In the Krosno and Skyba nappes, the Early Miocene deposits are composed of higher parts of the Krosno Formation, whereas in the marginal part of the Skyba Nappe they also include the Upper Menilite beds and Polyanytsya Formation (Eggenburgian). According to the majority of authors (see ŚWIDERSKI 1924; JABŁOŃSKI & WAGNER 1925; TOŁWIŃSKI 1925, 1928; ANDREYEVA-GRIGOROVICH & *al.* 1997; KOLTUN & *al.* 2005), there is sedimentological continuity between these formations.

Boryslav–Pokuttya Nappe

The Boryslav–Pokuttya Nappe is a narrow (up to 5 km) belt between the Skyba and Sambir nappes (Text-fig. 1B). It represents a complex set of superimposed thrust-sheets, composed of both flysch and molasse successions (see KOLTUN & *al.* 2005).

It is commonly accepted that the Early Miocene deposits of the Boryslav-Pokuttya Nappe are represented by the Upper Menilite Beds and the Polyanytsya and Vorotyshcha formations. According to GURZHYI (1969), GLUSHKO & KRUGLOV (1971), KRUGLOV (1978), and SMIRNOV & *al.* (2000), there is a sedimentary break between the Menilite and Polyanytsya formations, as suggested by the Rushor Conglomerate at the bottom of the Polyanytsya Formation. This conglomerate is regarded a basal conglomerate of a new sedimentary cycle. In our opinion the Rushor Conglomerate, up to 150 m thick, represents synsedimentary debris flow deposits.

Two facies zones of the salt-bearing Vorotyshcha Formation were distinguished: the internal Boryslav facies in the north-west and the external Rungur facies in the south-east (VIALOV 1965; VASHCHENKO & HNYLKO 2003; KORIN 2005). The Boryslav facies comprises the Polanytsya, Vorotyshcha and Stebnyk formations.

The Vorotyshcha Formation is subdivided into three parts. The lowest part, up to 1000 m thick, is represented by calcareous, grey shales and clays with intercalations of cross-bedded sandstones. Intercalations of salt (halite and kainite), gypsum and clast- to matrix-supported breccias form a characteristic component

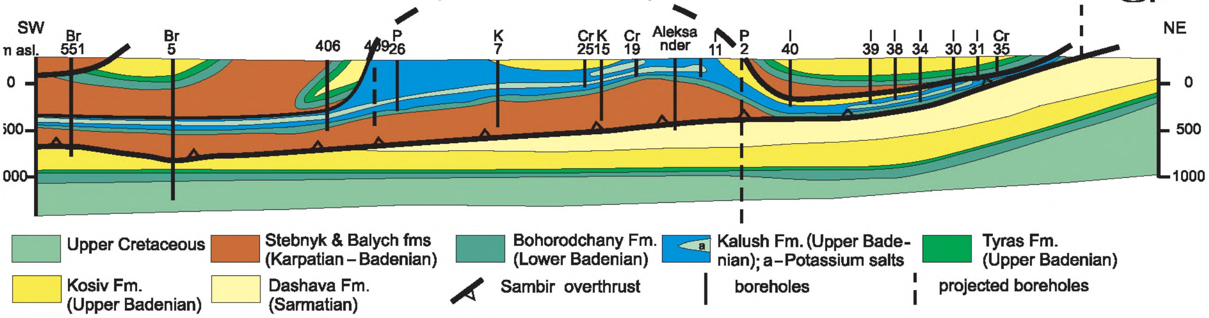

Fig. 2. Geological cross-section through the Sambir Nappe at the Kalush (after ANDREYEVA-GRIGOROVICH & *al.* 2003, simplified)

(PERYT & KOVALEVICH 1997). The redeposited material is represented by clasts and blocks of halite, anhydrite, Miocene clays and sandstones, as well as by Carpathian flysch rocks (Late Cretaceous variegated marls, Early Cretaceous black shales and sandstones).

The Truskavets (Zahirsk) Conglomerate forms the middle part of the formation. It is an up to 100 m thick complex of conglomerates, breccias and sandstones, with subordinate clay intercalations. Clasts are represented by green and red schists, yellowish dolomites, organodetritic limestones, red cherts, red conglomerates of verrucano type and fragments of brown bituminous shales, up to 10 m in diameter, similar to the Menilite Beds (TOŁWINSKI 1925, VIALOV 1965, GURZHYI 1969). The Truskavets Conglomerate is often regarded as equivalent of the Sloboda Conglomerate (e.g. SMIRNOV & *al.* 1993).

The highest part of the Vorotyshcha Formation, up to 700 m thick, is represented by grey, non-calcareous, gypsiferous shales and clays, with intercalations of grey, fine-grained sandstones, often with halite cement. Layers of sedimentary breccia occur sporadically.

The Vorotyshcha Formation usually represents the youngest member of the inner part of the Boryslav–Pokuttya Nappe; only locally does it pass up into the Stebnyk Formation.

In the Rungur (Pokuttya) facies area, only the lower part of the Vorotyshcha Formation is developed. Higher up, the succession is represented by the Sloboda Conglomerate and Dobrotiv Formation.

The precise age of the Vorotyshcha Formation is not yet established. Its lowest part yielded the nannofossils *Discoaster druggii* BRAMLETTE & WILCOXON and *Sphenolithus belemnos* BRAMLETTE & WILCOXON, and the foraminifers *Bolivina subdilitata* PISCHVANOVA, *Chilogumbelina gracillima* (ANDREAE) and *Cibicides boryslavensis* AISENSTAD. Such an assemblage suggests a Late Eggenburgian age for at least the lowest part of the Vorotyshcha Formation (ANDREYEVA-GRIGOROVICH & *al.* 1995). ANDREYEVA-GRIGOROVICH & *al.* (1997), however, dated the whole formation as Ottnangian. According to SMIRNOV & *al.* (2000), the lowermost part of the formation represents the Eggenburgian and its higher part belongs to the Ottnangian, which is confirmed by the presence of *Globoquadrina langhiana* CITA & GELATI and *G. dehiscens* (CHAPMAN, PARR & COLLINS). According to the zonal scheme for Neogene Tethys deposits (MARTINI 1971) the Vorotyshcha Formation belongs to the NN2 and NN3 nannoplankton zones (Early and Middle Burdigalian).

Recently KOLTUN & *al.* (2005) suggested the following succession for the Miocene deposits of the Boryslav–Pokuttya Nappe: Menilite flysch with black shales, Polyanytsya sandstones and shales, Vorotyshcha salt-bearing deposits with intercalations of Sloboda Conglomerate and Dobrotiv Sandstone and Stebnyk variegated shales and sandstones.

Sambir Nappe

The Sambir Nappe, referred to in Romania as the Sub-Carpathian unit, and in Poland as the Stebnik Nappe, is composed of lower–middle Miocene (?Ottnangian–Karpatian to Sarmatian) folded deposits that are overthrust onto Sarmatian deposits of the Bilche–Volytsya Zone (OSZCZYPKO & *al.* 2006). Traditionally the Sambir Nappe, up to 24 km wide (Text-fig. 1B), is regarded as a big synform located at the front of the Boryslav–Pokuttya Nappe. In the Kalush Salt Mine cross–section (Text-fig. 2, see also ANDREYEVA-GRIGOROVICH *al.* 2003), the Sambir Nappe is built up of three thrust-sheets (700 m thick) overthrust flatly onto the Dashava Formation (Sarmatian) of the Outer Carpathian Foredeep. These thrust-sheets are composed of the following formations: Stebnyk and Balych (Karpatian-Badenian), Bohorodchany (Lower Badenian), Kalush (Upper Badenian), Tyras (Upper Badenian), Kosiv (Upper Badenian) and Dashava (Sarmatian).

The lithostratigraphy of the basal part of the Sambir Nappe is controversial. According to BUROV (1966), BUROV & *al.* (1978), KRUGLOV (1978), ANDREYEVA-GRIGOROVICH & *al.* (1997) and VASHCHENKO & HNYLKO (2003), the succession starts with the Vorotyshcha Formation. This opinion is based on the Gvizd 1 borehole (in the town of Nadvirna) where the Vorotyshcha Formation is covered by the Sloboda Conglomerate. Similar relationships were also observed in the Uroz 6 borehole (north-east of the Boryslav–Pokuttya Nappe), which pierced the Vorotyshcha Formation beneath the Dobrotiv Formation. According to SMIRNOV & *al.* (2000) and KOLTUN & *al.* (2005), the Sambir Nappe succession starts with the Early Miocene Sloboda Conglomerate, characterised by the presence of exotic blocks of green phyllites, black schists, white limestones, dolomites, and the lack of Carpathian flysch material (SMIRNOV & *al.* 1993). ANDREYEVA-GRIGOROVICH & *al.* (1997) dated the Sloboda Conglomerate as Early Ottnangian. The Sloboda Conglomerate passes up into shallow-water brackish clays, mudstones and sandstones of the Ottnangian Dobrotiv Formation, up to 400 m thick (ANDREYEVA-GRIGOROVICH & *al.* 1997). The Dobrotiv Formation is followed by variegated marls and sandstones of the Stebnyk Formation, also dated as Ottnangian. Both the Dobrotiv and Stebnik formations are famous for their animal footprints (birds, gazelles, Hippidae) in the Delatyn section (VIALOV

1966). The upper part of the Stebnyk Formation belongs to the Late Ottnangian and Karpatian (Late Burdigalian and Early Langhian age – NN4 Zone, ANDREYEVA-GRIGOROVICH & *al.* 1997).

The Stebnyk Formation passes up into greenish-grey clays, mudstones and poorly cemented sandstones of the Balych Formation (CIZANCOURT 1929). There are several misunderstandings and contradictions concerning this latter formation (see VIALOV 1965 and references therein). BUJALSKI (1930) regarded the Balych Formation as the northern facies of the upper part of the Stebnyk Formation.This was lately supported by its Karpatian/Lower Badenian (NN4) age (ANDREYEVA-GRIGOROVICH & *al.* 1997). In places, however, the variegated marls of the Stebnyk lithofacies also represent the NN5 Zone, suggesting a diachronous boundary between the red and grey deposits.

In the area of Kalush, the Balych Formation in the Sambir Nappe passes up (see DZHINORIDZE 1979, 1980; ANDREYEVA-GRIGOROVICH & *al.* 2003) into the Bohorodchany Formation (100-250 m thick), which consists of grey clays, marls and sandstones, with intercalations of *Lithothamnium* limestones and tuff layers. The basal part of the formation yielded the fauna with *Pseudamussium denudatum* and a rich planktonic foraminiferal fauna (see VIALOV 1965, and references therein), as well as Badenian calcareous nannofossils of the NN5 Zone (ANDREYEVA-GRIGOROVICH & KULCHYTSKY 1985). The Bohorodchany Formation passes up into the evaporitic sequence (Kalush and Tyras formations), represented by gypsum and salt with intercalations of grey marls. In the Kalush Salt Mine the thickness of the salt-bearing deposits is up to 400 m, while the thickness of the Tyras Formation is around 10-15 m (Text-fig. 2, see also ANDREYEVA-GRIGOROVICH & *al.* 2003). In the north-western part of the Sambir Nappe, the evaporitic sequence has not been found, which suggests local unfavourable conditions in this basin for evaporite sedimentation. In view of the lack of evaporites in this area, some authors (eg. SMIRNOV & *al.* 2000; VASHCHENKO & HNYLKO 2003) widen the definition of the Balych Formation to embrace all of the Middle Miocene deposits of the Sambir Nappe. Consequently, the Bohorodchany, Kosiv and Dashava formations (up to 2000 m thick) were all included in the Balych Formation.

The age of the evaporitic sequence has been discussed for a long time. An Early Badenian age based on micropalaeontological studies was proposed by SIEROVA (1950). Several authors (e.g., BUROV & *al.* 1978; KRUGLOV 1978) regarded the Kalush salts as being of Early Miocene age, and stated that the salt was older than the Tyras gypsum. DZHINORIDZE (1980) correlated the gypsum horizon (Tyras Formation) with the salt sequence and regarded all of them as of Badenian age. More recently, the evaporites and related deposits have been included in the Tyras Formation (PETRICZENKO & *al.* 1994). Calcareous nannoplankton studies (ANDREYEVA-GRIGOROVICH & KULCHYTSKY 1985) showed that the salt deposits were formed some time between the NN5 and NN6 zones. Subsequent research by ANDREYEVA-GRIGOROVICH & *al.* (1997) suggested that the evaporitic sequence could also embrace the NN5 Zone. The most recent biostratigraphic data (ANDREYEVA-GRIGOROVICH & *al.* 2003) showed that the salt deposits of the Carpathian Foredeep in the territory of Ukraine and Poland originated during the same period, and correspond to the Late Badenian NN6 Zone and undivided NN6-NN7 zones. The uppermost part of the sub-evaporitic beds belongs to the boundary between the NN5 and NN6 zones, although locally (Bochnia Salt Mine) only the NN6 Zone was proved.

The evaporitic deposits are capped by grey clays and sandstones with tuffite intercalations (Kosiv Formation; up to 200 m) of late Badenian–earliest Sarmatian age (NN6-NN7 zones), followed by grey clays and sandstones with tuffite intercalations of the Sarmatian Dashava Formation. North of Dobromil, in the north-west part of the Sambir Nappe, the Dashava Formation is overlain by the Radych Conglomerate, up to 150 metres thick, characterized by exotic rocks (limestones, metamorphic schists) and clasts of Menilite shales and cherts. The conglomerates are regarded as the youngest deposits of the Sambir Nappe.

SECTIONS STUDIED

The following sections of the Ukrainian Carpathians and of the folded Miocene Zone have been studied:

I) Delatyn–Lanchyn area (Text-figs 1, 3-9): A. Delatyn–Zarichye section; B. Oslava creek section; C. Lanchyn section.

II) Petranka area (Text-figs 1, 10-12): D1. Petranka north village section; D2. Petranka south village section; D3. Uhryniv section.

III) Dobromil area (Text-figs 1, 13-15): E1. Bonevychi section; E2. Radych section.

IV) Mykhailevichi section F (Text-fig. 16).

I. Delatyn–Lanchyn area (Text-figs 1, 3-9)

A. *The Delatyn–Zarichye section.* It is situated along the Prut River and contains the youngest deposits of the Skyba Nappe. The exposures are located in the river-bed and on the right bank of the river. The exposed rocks consist of black, dark grey and brownish-grey calcareous mudstones with intercalations of "Kliwa type" medium- to thick-bedded fine-grained sandstones (Text-figs 4, 5A, 5B – section A1) with spo-

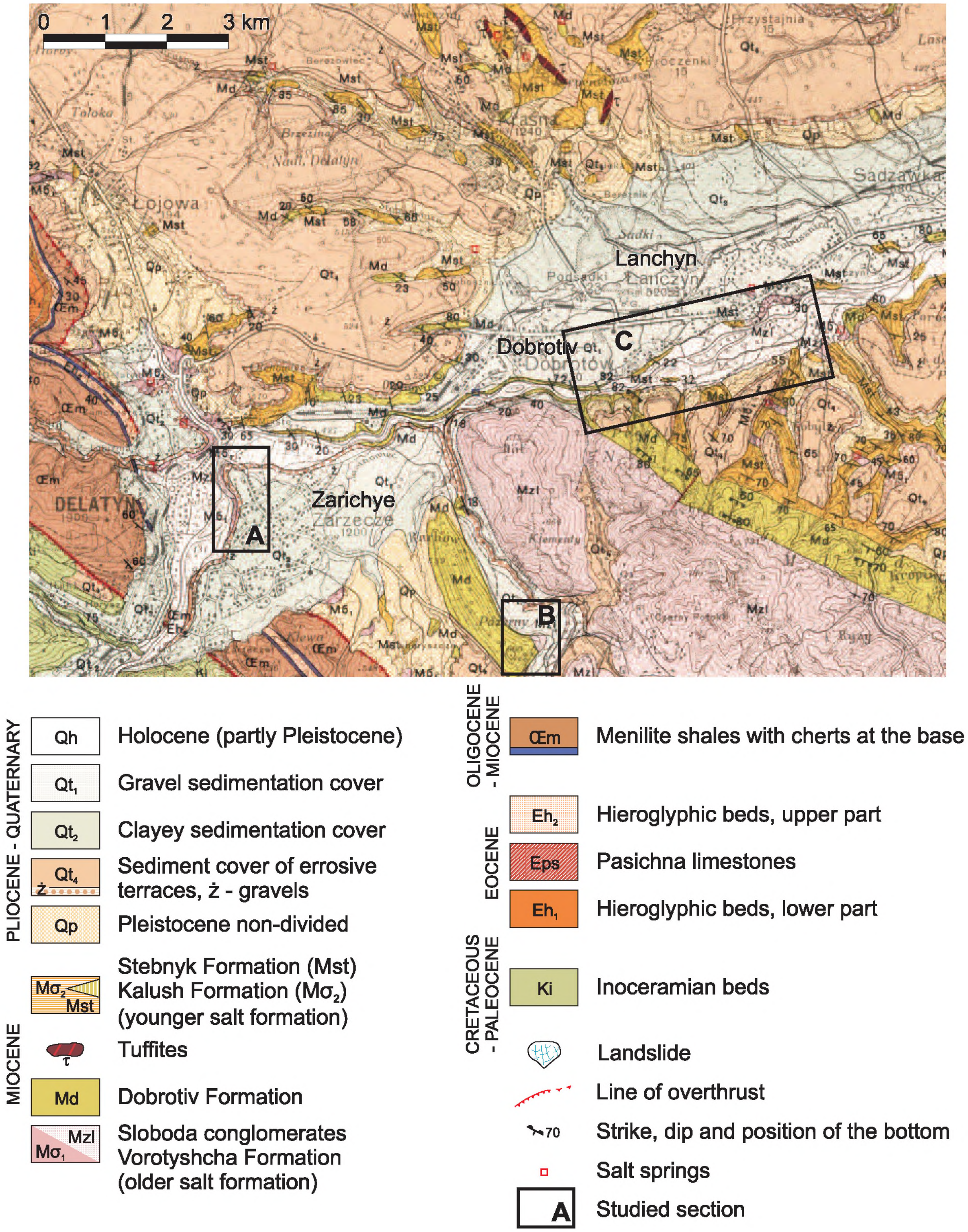

Fig. 3. Geological map of Delatyn-Lanchyn area (after BUJALSKI 1938)

radic beds of sphaerosiderite. The flute casts show that the palaeocurrent direction was towards the south-east (160°). These beds (samples D1-D3) were described by BUJALSKI (1938) as the Upper Menilite subformation of the Menilite Formation, up to 400 m thick (ANDREYEVA-GRIGOROVICH & *al.* 1997). Towards the north (250-300 m), on the right bank of the river, crop out grey marly shales with intercalations of thin-bedded sandstones, which belong to the south-dipping (in overturned position) Polanytsya Formation (Text-fig. 4 – section A2, sample Dx). About 150 m downstream we found the overthrust of the Skyba Nappe onto the massive dark grey mudstones of the Vorotyshcha Formation (Text-fig. 4 – section A3, samples D4 and D5) of the Boryslav–Pokuttya Nappe. These mudstones contain intercalations of brecciated dark grey marly shales (Text-fig. 5C) with gypsum veins and intercalations (up to 1 m thick) of matrix-supported exotic conglomerates (debris flow) with block of limestones and Menilite shales. Higher up in the section the dark grey shales are overlain by thick-bedded (Text-fig. 5D), medium- to very coarse-grained, poorly cemented sandstones and fine conglomerates (see GURZHYI 1969). They pass upwards into debris flow deposits with clasts of green Precambrian slates, Menilite shales and blocks of Mesozoic limestones. These conglomerates with exotic material could be an equivalent of the Truskavets Conglomerate of the middle part of the Vorotyshcha Formation (see GURZHYI 1969).

B. *Oslava section.* It is situated along the Oslava Stream (right-hand tributary of the Prut River, five kilometres east of Delatyn). This section belongs to the Sloboda Rungurska Anticline (up to 4 km wide) (BUJALSKI 1938), of the Boryslav–Pokuttya Nappe. Its southern limb displays the boundary between the Sloboda Conglomerate and the Dobrotiv Formation. This fining- and thinning-upward sequence begins with the Sloboda Conglomerate (see OSZCZYPKO & *al.* 2006), composed of pebbles and boulders of the Proterozoic meta-argillites (mainly green, red and variegated phyllites), quartzites, diabases, dolomites and Jurassic limestones, derived from the platform basement of the Carpathian Foredeep, as well as Menilite shales and cherts derived from the Flysch Carpathians (see GURZHYI 1969; OSZCZYPKO & *al.* 2006). The estimated thickness of the Sloboda Conglomerate varies roughly from 1000 m up to 2000 m (GURZHYI 1969). The boundary between the Sloboda conglomerates and the Dobrotiv Formation is exposed at the Oslava Creek outflow to the Prut River (Text-fig. 5E). There, the dark, medium-grained clast- to matrix-supported conglomerates pass up into a dark sedimentary breccia of black shales and, finally, to dark-grey, fine-grained, cross-laminated sand-

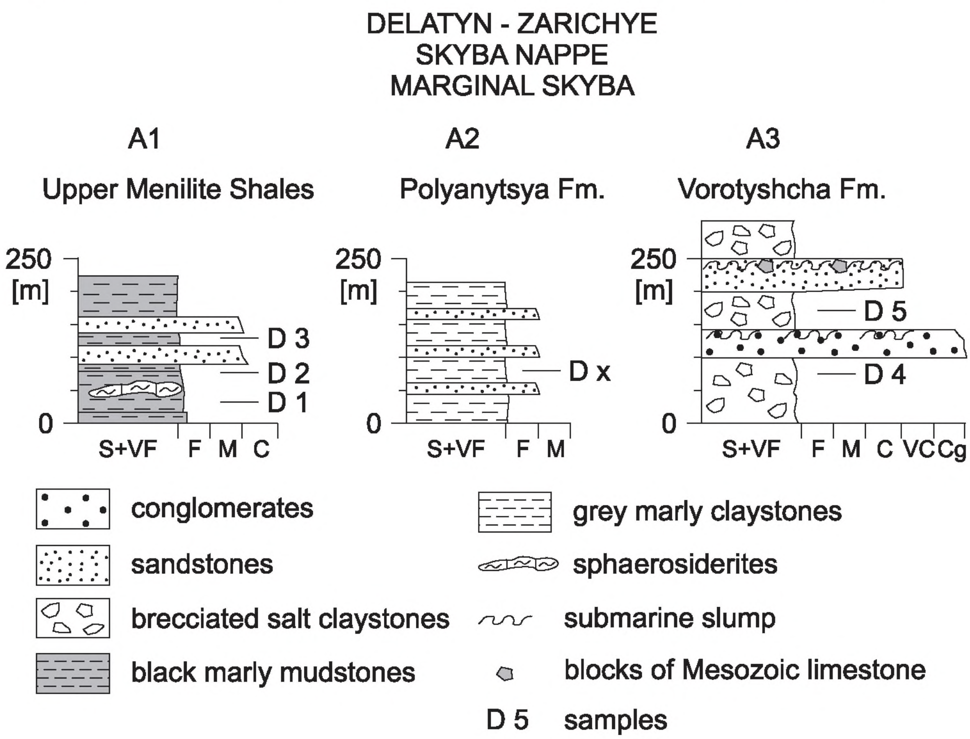

Fig. 4. Simplified profiles of Zarichye section with location of samples

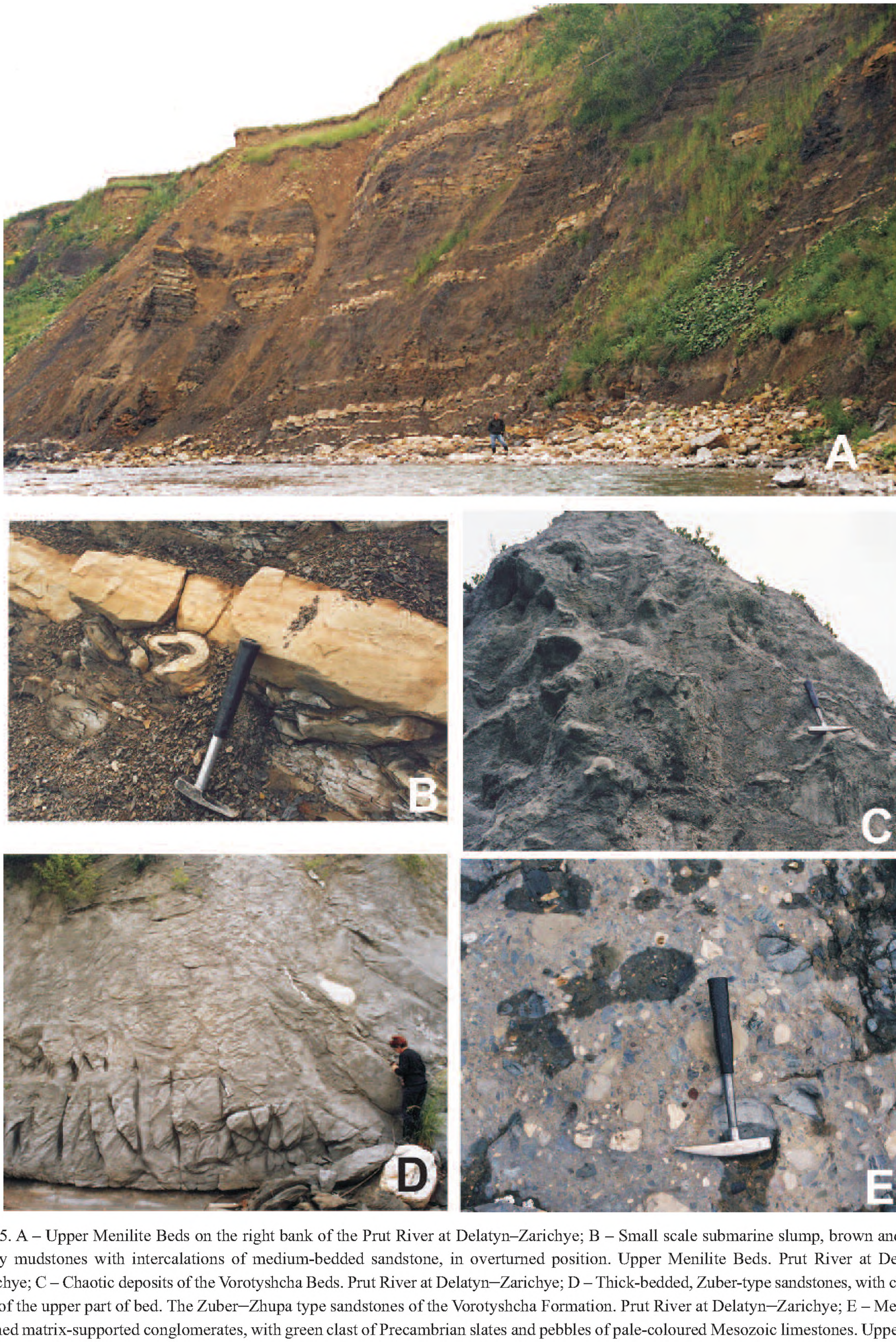

Fig. 5. A – Upper Menilite Beds on the right bank of the Prut River at Delatyn–Zarichye; B – Small scale submarine slump, brown and grey marly mudstones with intercalations of medium-bedded sandstone, in overturned position. Upper Menilite Beds. Prut River at Delatyn/ Zarichye; C – Chaotic deposits of the Vorotyshcha Beds. Prut River at Delatyn–Zarichye; D – Thick-bedded, Zuber-type sandstones, with chaotic part of the upper part of bed. The Zuber–Zhupa type sandstones of the Vorotyshcha Formation. Prut River at Delatyn–Zarichye; E – Medium-grained matrix-supported conglomerates, with green clast of Precambrian slates and pebbles of pale-coloured Mesozoic limestones. Uppermost part of the the Sloboda Conglomerate on the Oslava River near Delatyn

stones. The sandstones are followed by a succession, only a few metres thick, of thin-bedded sandstones and mudstones. The higher part of the section consists of channelized thick- and very thick-bedded, amalgamated, medium- to coarse-grained sandstones, with thin intercalations of green and reddish mudstones

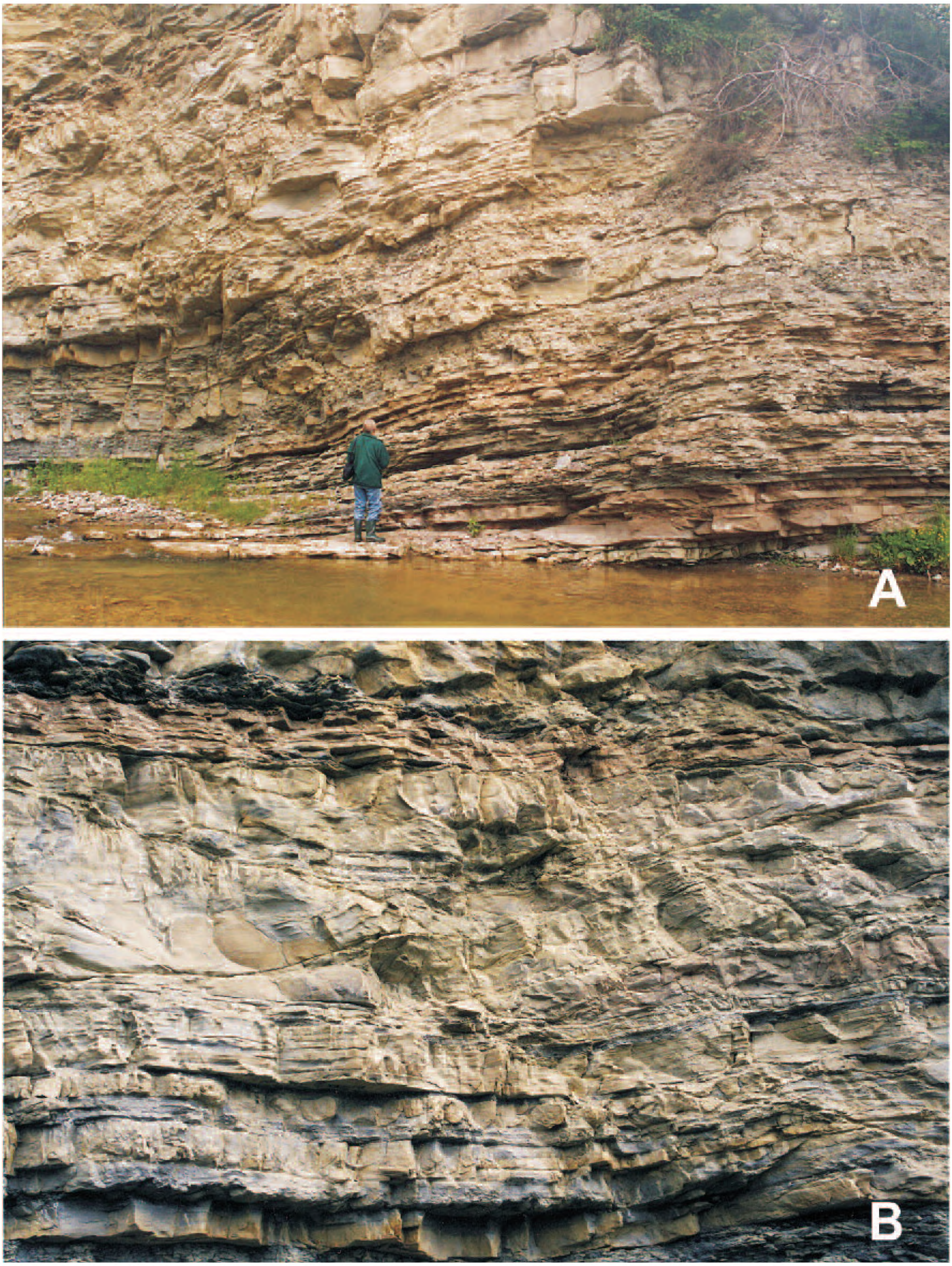

Fig. 6. A – Thickening- and coarsening-up deltaic sequence of the basal part of the Dobrotiv Formation at the Oslava River near Delatyn; B – Details of Text-fig. 6. A, very thick-bedded, channelized sandstones

(Text-figs 6A, 6B). The basal surface of the sandstone beds reveals flute cast and load cast structures. The Dobrotiv Formation, 600-800 m thick, is known from vertebrate (birds, artiodactyls and felines) footprints as well as rain-prints (VIALOV 1966; GURZHYI 1969; ANDREYEVA-GRIGOROVICH & al. 1997). The Dobrotiv sandstones are composed of 80% quartz, with an admixture of exotic crystalline rocks and carbonates,

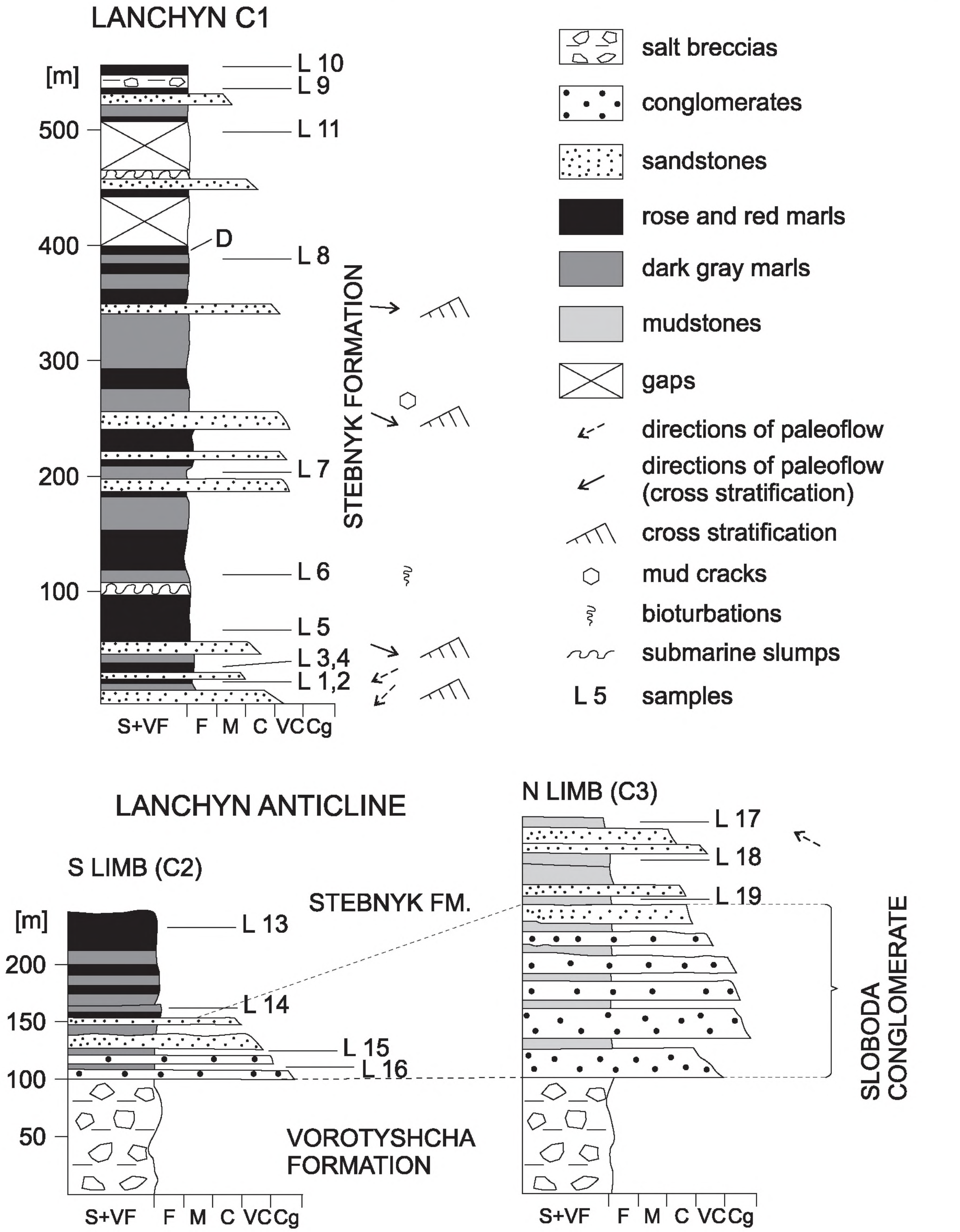

Fig. 7. Lithostratigraphic log of Lanchyn section with sample levels

Fig. 8. Lanchyn on Prut River. A. – The Dobrotiv-type thick-bedded, poorly sorted and poorly cemented sandstones of lowermost part of the Stebnyk Formation; B – Rose-coloured marlstones with thin-bedded sandstones. Lower part of the Stebnyk Formation; C – Rose-coloured and grey marlstone with intercalation of thick-bedded sandstone. Lower part of the Stebnyk Formation; D – Marls with intercalation of thick- to medium-bedded sandstones (channel infill), middle part of the Stebnyk Formation. Right bank of the Prut River; E – Rose-coloured and grey marlstones with interacalation of thin-bedded sandstones with clastic dykes. Middle part of the Stebnyk Formation; F – Mud-cracks at the top of medium-bedded siltstone. Middle part of the Stebnyk Formation

Fig. 9. A – Brecciated dark grey marls with intercalation of anhydrites. Large olistolith of Vorotyshcha Formation in the upper part of the Stebnyk Formation, at the Lanchyn on Prut River; B – Fine-grained conglomerates and thick-bedded sandstones of the Sloboda Conglomerate. Northern limb of the Lanchyn Anticline near the bridge at Lanchyn. C – Fine- to medium-grained matrix- to clast-supported conglomerates. Sloboda Conglomerate, northern limb of the Lanchyn Anticline near the bridge at Lanchyn

and sometimes contain up to 3-5 % of glauconite (GURZHYI 1969).

C. *Lanchyn section.* This section is situated on the northern limb of the Sloboda Rungurska Anticline and exposes the younger deposits of the Boryslav–Pokuttya succession. The lowermost part of the succession, with the transition from the thick-bedded Dobrotiv sandstone (Text-figs 7, 8A – section C1) to the Stebnyk Formation (Text-figs 7, 8B – section C1), is composed of red (sample L1) and dark grey calcareous mudstones (samples L2 to L5) with thin intercalations of thin- to thick-bedded (Text-fig. 8C) fine-grained sandstones. Usually red mudstones are located at the top of grey mudstones. There are also sporadic intercalations of black shales. A few dozen metres higher in the section, intercalations of thick-bedded, Dobrotiv-type sandstones (1.5-2.0 m) occur in the lower part of the Stebnyk Formation. These fine-grained sandstones display large-scale trough cross-bedding, low-angle cross-bedding and parallel bedding. The flute casts reveal paleotransport direction from the north-east (60-70°), whereas the cross-lamination shows palaeoflow from the north-west (290-300°). In the right bank of the Prut River, about 100 m above the base of the Stebnyk Formation, occur south-dipping beds (Text-fig. 8D), and in the corresponding bed-rock of the river appear 50-60 cm thick sandstone beds deformed by a submarine slump. The slump horizon is capped by bioturbated grey, marly mudstones (Text-fig. 7 – section C1, sample L6) with thin-bedded sandstones with clastic dykes (Text-fig. 8E). The grey mudstones pass up into red and grey marly mudstones (sample L7) with several intercalations of thick-bedded sandstones. Thick-bedded sandstones with mud-cracks (Text-figs 7, 8F – section C1) occur again 250 m above the base of the formation. Higher up, the succession is dominated by the rose-coloured marls, with sporadic intercalations of grey marls (Text-fig. 7 – section C1, sample L8) and layers of thick-bedded sandstones (up to 2 m) with an horizon of muddy clasts. The trough cross-bedding show palaeotransport to the east (110°). In the middle part of the Lanchyn section (500 m above the base and 70 m beneath the cable bridge the Stebnyk variegated deposits (Text-fig. 7 – section C1, samples L9 and L11) contain a bed of salt breccia (at least 10 m thick, see Text-fig. 9A) with gypsum veins, which was probably derived from the Vorotyshcha Salt Formation (sample L10). The axis of the anticline is located in the centre of the village of Lanchyn, close to the bridge over the Prut River. The axial part of the anticline is composed of grey brecciated mudstones of the Vorotyshcha Formation, and its limbs are formed by the Sloboda Conglomerate (50-100 m thick). On the southern limb of the anticline, the debris flow conglomerates (Text-figs 7, 8B, 8C – section C2) pass up into a few thick-bedded Dobrotiv-type sandstones and grey shales (Text-fig. 7 – section C2, samples L15 and L16) and typical rose-coloured marls of the Stebnyk Formation (Text-fig. 7 – section C2, samples L13 and L14). Beneath the bridge, in the northern limb of the anticline (Text-fig. 7 – section C3), the Sloboda Conglomerate passes up into an at least 50 m thick packet of the overturned blue-grey, non-calcareous shales (Text-fig. 7 – section C3, samples L17 up to L 19) known as the Lanchyn blue complex (VIALOV 1965), with sporadic intercalations of thick-bedded coarse-grained sandstones, which display palaeotransport from the east-southeast (110°). In the Lanchyn section the thickness of the Stebnyk Formation is at least 600 m.

II. Petranka area (Text-figs 10-12)

D1. *Petranka north village section.* This section is situated along the Berezhnytsya Stream (Text-fig. 10). It contains the Stebnyk and Balych formations of the Sambir Nappe, represented by an at least 160 m thick succession of dark grey marly mudstones with a few intercalations of rose-coloured marls (Text-fig. 11 – section D1, samples P1 and P2). The dark grey marls of the Balych lithofacies contain several thick-bedded (0.8 m to 4.0 m) massive, medium-grained, muscovite sandstones.

D2. *Petranka south village section* (Text-fig. 10). The uppermost part of the Stebnyk Formation, composed of an at least 10 m thick bunch of red marls, crops out in the lower part of the section. It is followed by a 15-m thick unit of dark grey laminated mudstones (Text-fig. 11 – section D2, sample P3) with gypsum intercalations. The upper half of the section consists of grey marls with intercalations of salt-gypsum breccias (Kalush Formation ?). These chaotic sediments, at least 25 m thick, contain folded beds with submarine slumps.

D3. *Uhryniv section.* It is situated downstream of the Berezhnytsya Stream, ca 200-210 m beneath the inflow of the Buchkiv Creek (Text-fig. 10). The base of the section is composed of red marls, ca 10 m thick, which represent the top of the Stebnyk Formation. The red marls are covered by a unit of dark grey laminated Balych-type mudstones, a few metres thick (Text-fig. 11 – section D3, sample P12). A few metres higher in the section, these mudstones (Text-fig. 11 – section D3, sample P11) form the core of a small anticline (Text-figs 12A, 12B), with

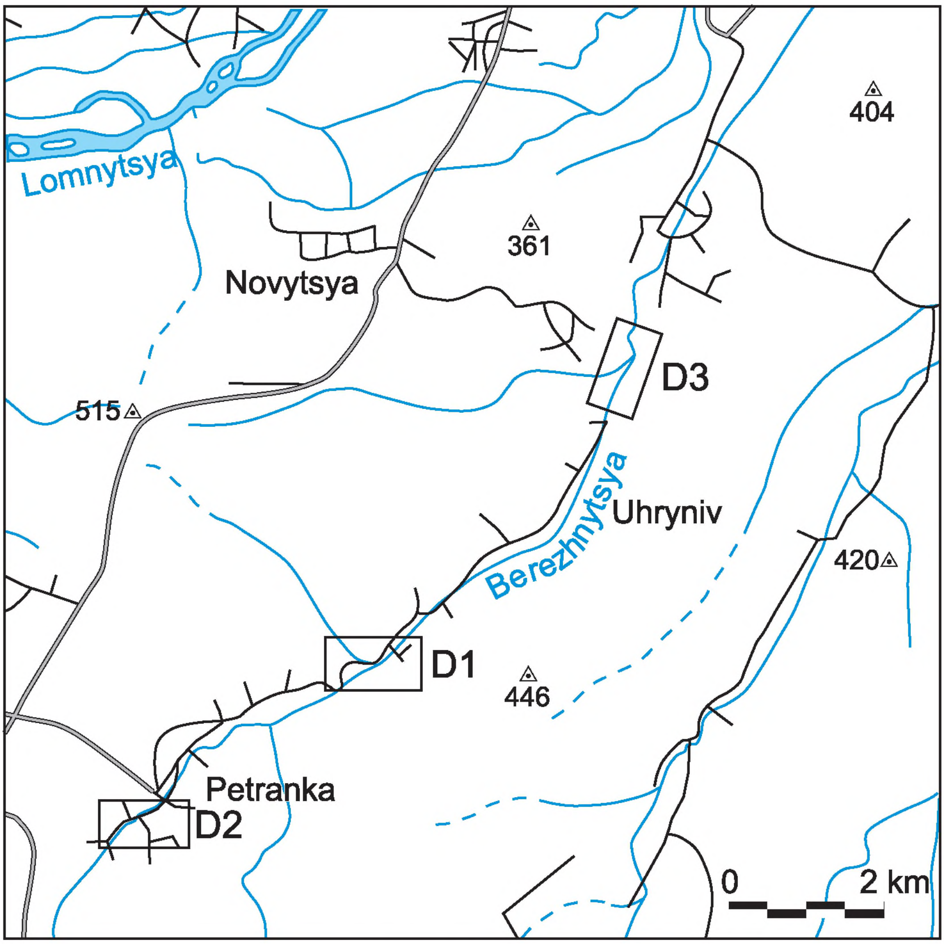

Fig. 10. Sketch-map of the Pertranka area

a ca 1.5 metres-thick shear zone with an imbricated fold at the top (Text-fig. 12C). This exposure shows brecciated marlstones with numerous large clasts of rose-coloured and brown mudstones of the Stebnyk type (Text-fig. 11 – section D3, sample P9), capped by green shales (Text-fig. 11 – section D3, sample P10). The thickness of these transitional beds between the Stebnyk and Kalush lithofacies is about 10 m. Higher up in the section, stratified, noncalcareous mudstones (Text-fig. 11 – section D3, sample P8) and anhydrite claystones (Text-fig. 12D-E) are followed by grey, saliferous, brecciated claystones with gypsum veins. These 60 m-thick brecciated rocks contain intercalations of laminated mudstones (Text-fig. 11 – section D3, sample P7, P6) with thin layers of gypsum. The saliferous claystones are exposed up to the inflow of the Buchkiv Brook. The upper portion of the Sambir succession in this section is exposed c. 100 m southwards, close to the bridge over the Berezhnytsya Stream (Text-fig. 12F). These deposits are represented by green to grey calcareous shales (Text-fig. 11 – section D3, samples P4 and P5) with sporadic intercalations of thin-bedded sandstones and siltstones, which could be correlated with the Kosiv Formation.

III. Dobromil area (Text-figs 13-15)

E1. *Bonevychi section*. The section is situated along the Vyrva Stream near the town of Dobromil (Text-fig. 13, E1). For a long time the Bonevych section was regarded as the typical section of the Balych lithofacies in the Dobromil area (see also VASHCHENKO & HNYLKO 2003; JANKOWSKI & *al.* 2004). However, according to our present study, this section represents the youngest part of the Sambir succession (Dashava Formation). This section displays an at least 50 m-thick sequence of grey marly mudstones (Text-fig. 14 – section E1, samples Bo1 up to Bo 4) with intercalations of thin- to medium-bedded fine-grained, turbiditic sandstones (Text-fig. 15B). There are also some beds of thick-bedded sandstones with load casts at the base (Text-fig. 15C), as well as pebbly mudstones, with flysch-derived pebbles. It is important to state that a 2 m thick layer of dacite tuffites was found

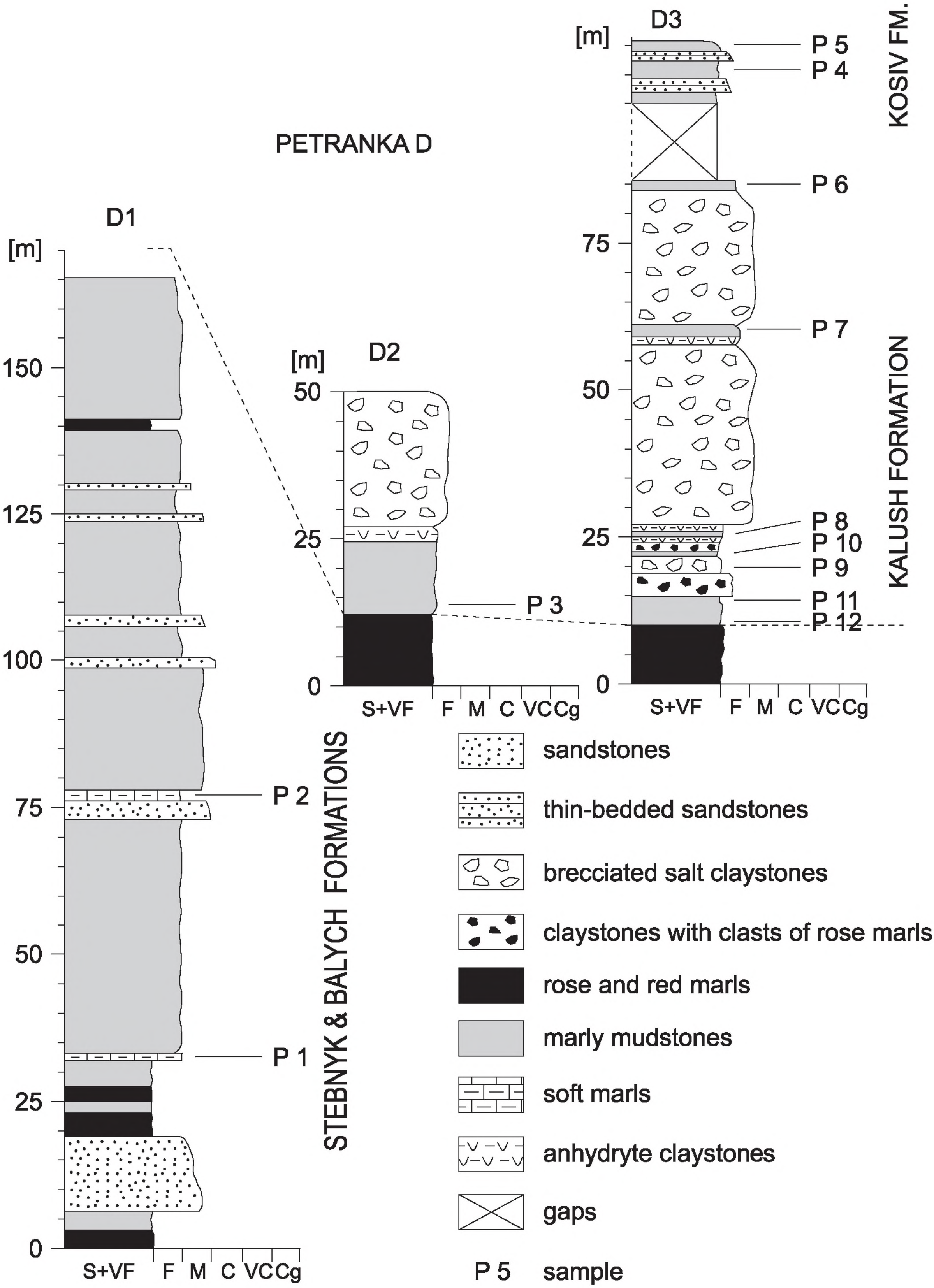

Fig. 11. Lithostratigraphic logs of the Petranka area

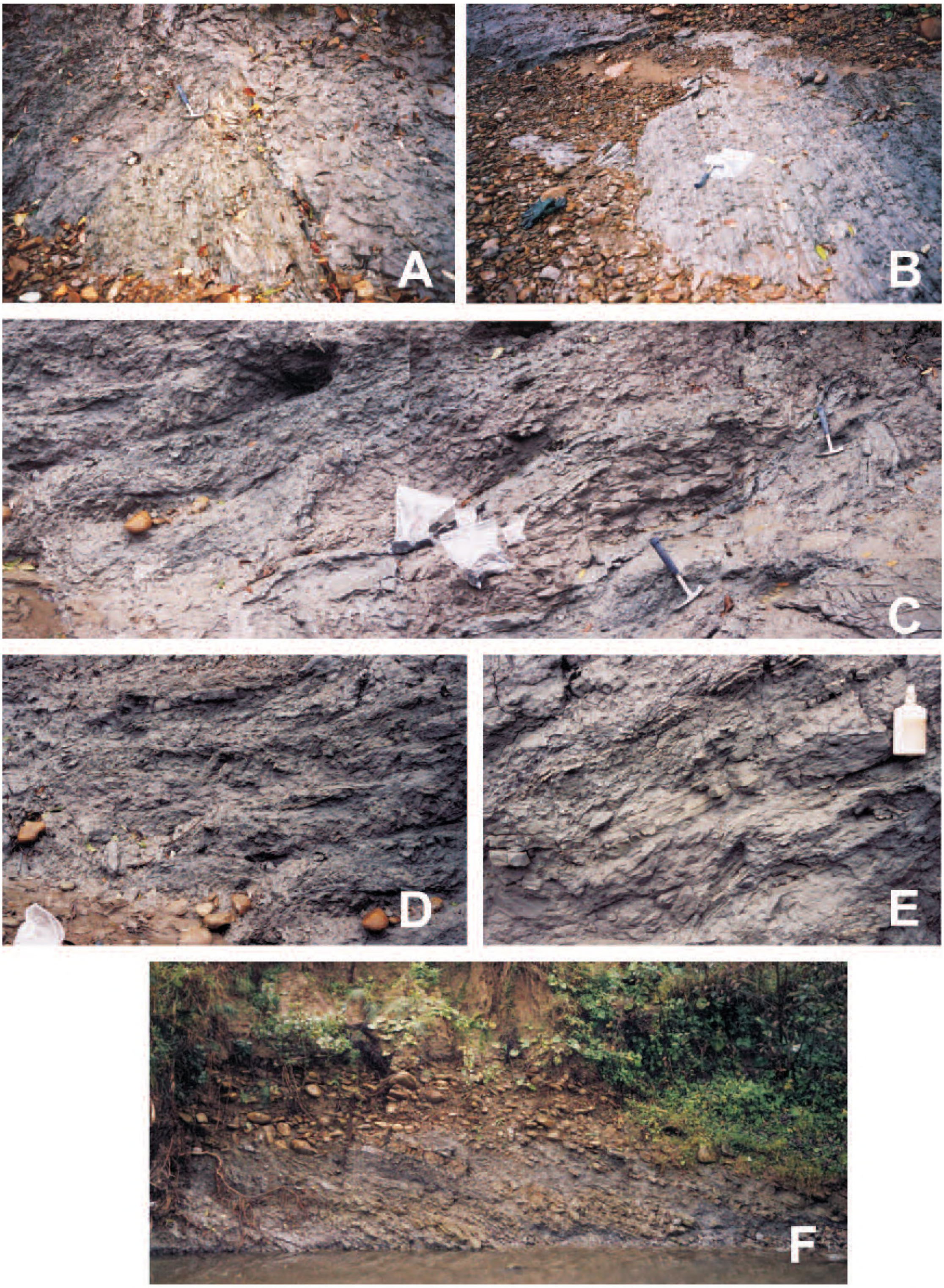

Fig. 12. A – Dark grey laminated mudstones of Balych type lithofacies in core of a small anticline. Lower Berezhnytsya Creek at Petranka; B – Dark grey laminated mudstones of Balych-type lithofacies; C – Brecciated rose-coloured and brown mudstones with numerous clasts of rose-coloured Stebnyk Marls. Lower Berezhnytsya Creek at Petranka; D –Stratified mudstones and anhydrite claystones of the Kalush Formation. Berezhnytsya Creek beneath the Buchkiv Brook outlet; E – Stratified mudstones and anhydrite claystones of the Kalush Formation. Berezhnytsya Creek beneath the Buchkiv Brook outlet. F – Grey marly claystones with intercalations of thin-bedded sandstones of the Kosiv Formation. Berezhnytsya Creek above the Buchkiv Brook outlet

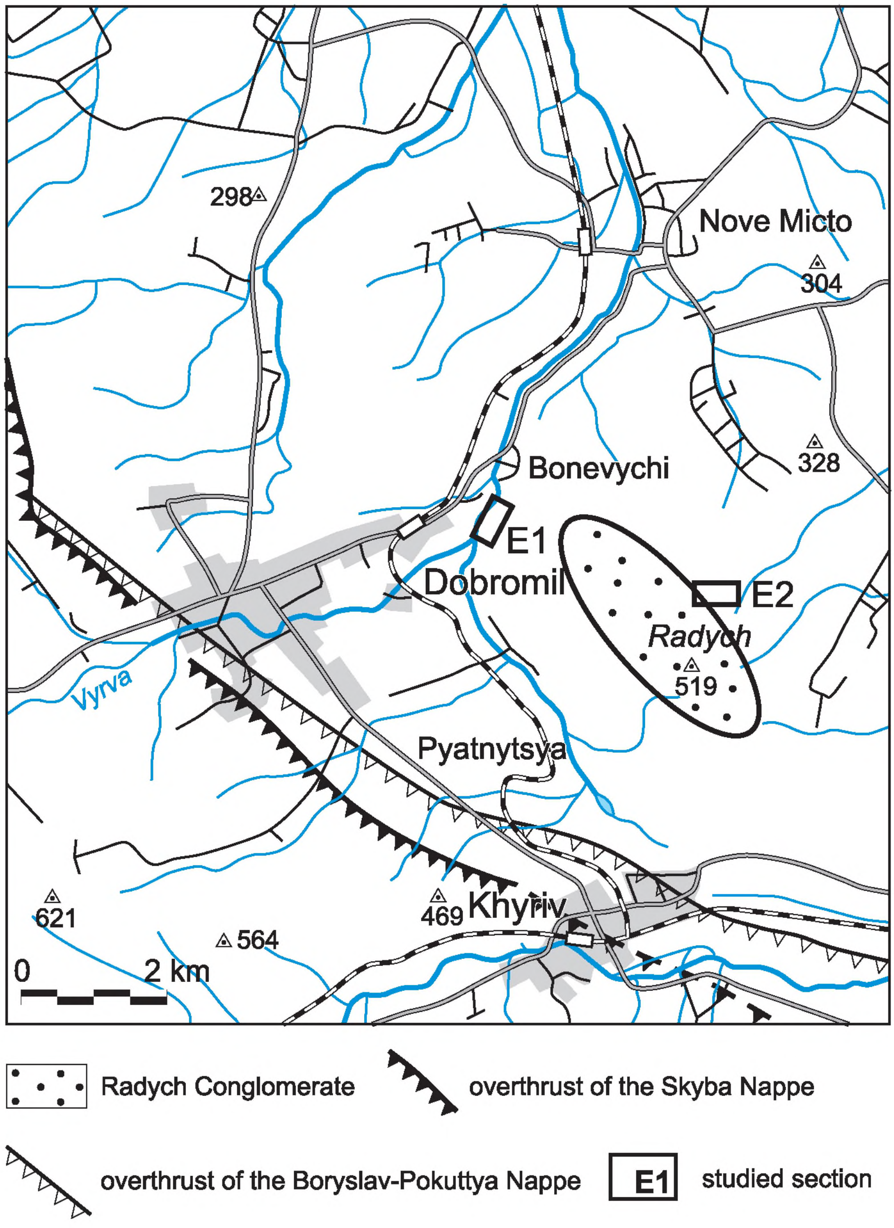

Fig. 13. Tectonic sketch-map of sections studied in Dobromil area (Bonevychi and Radych sections)

in this section (see VIALOV 1965). The Dashava Formation is followed by the Radych Conglomerate.

E2. *Radych section*. This section is situated along the road on the north-eastern slope of the Radych Hill where the Radych Conglomerate is exposed (Text-fig. 13 – section E2). It is represented by poorly cemented conglomerates with intercalations of light grey sandstones and marly clays (Text-fig. 14 – section E2, samples N1-2 and N3-4). The conglomerates contain flat ellipsoidal pebbles and cobbles (Text-fig. 15D). The imbricated clasts display palaeotransport towards the south-east. The conglomerates are composed of flysch-derived pebbles of Menilite-type black shales, cherts and quartz-glauconite non-calcareous sandstones, as well as exotic rocks (limestones). The conglomerates display coarsening- and thickening- upwards sequences.

IV. Mykhaylevychi section F (Text-fig. 16)

This section is situated along the road-cutting in the village of Mykhaylevychi, about 9 km north-east of Drohobych. This small section is composed of grey, marly shales with intercalations of thin-bedded sandstones (samples M1-4), beneath the flysch-derived conglomerates of the Radych type.

NANNOFOSSIL BIOSTRATIGRAPHY

Methods

Calcareous nannofossils. Smear slides were prepared from 62 samples, using a decantation method (separated fraction 3-30 μm) in the following way: the heavy fraction was allowed to settle for 3 minutes in a 45-mm water-column; the fine fraction for 45 minutes. Slides were viewed under an Axilab/Carl Zeiss light microscope at 1000 magnification. All index species were photographed and are presented in Plates 1-3. The standard nannoplankton zonations of MARTINI (1971), MARTINI & WORSLEY (1970), and SPROVIERI & *al.* (2002) were used.

Early Miocene

It comprises the upper Egerian, Eggenburgian, Ottnangian and Karpatian stages. Sediments of these stages contain associations of zones NN2, NN3 and of the lower NN4 Zone.

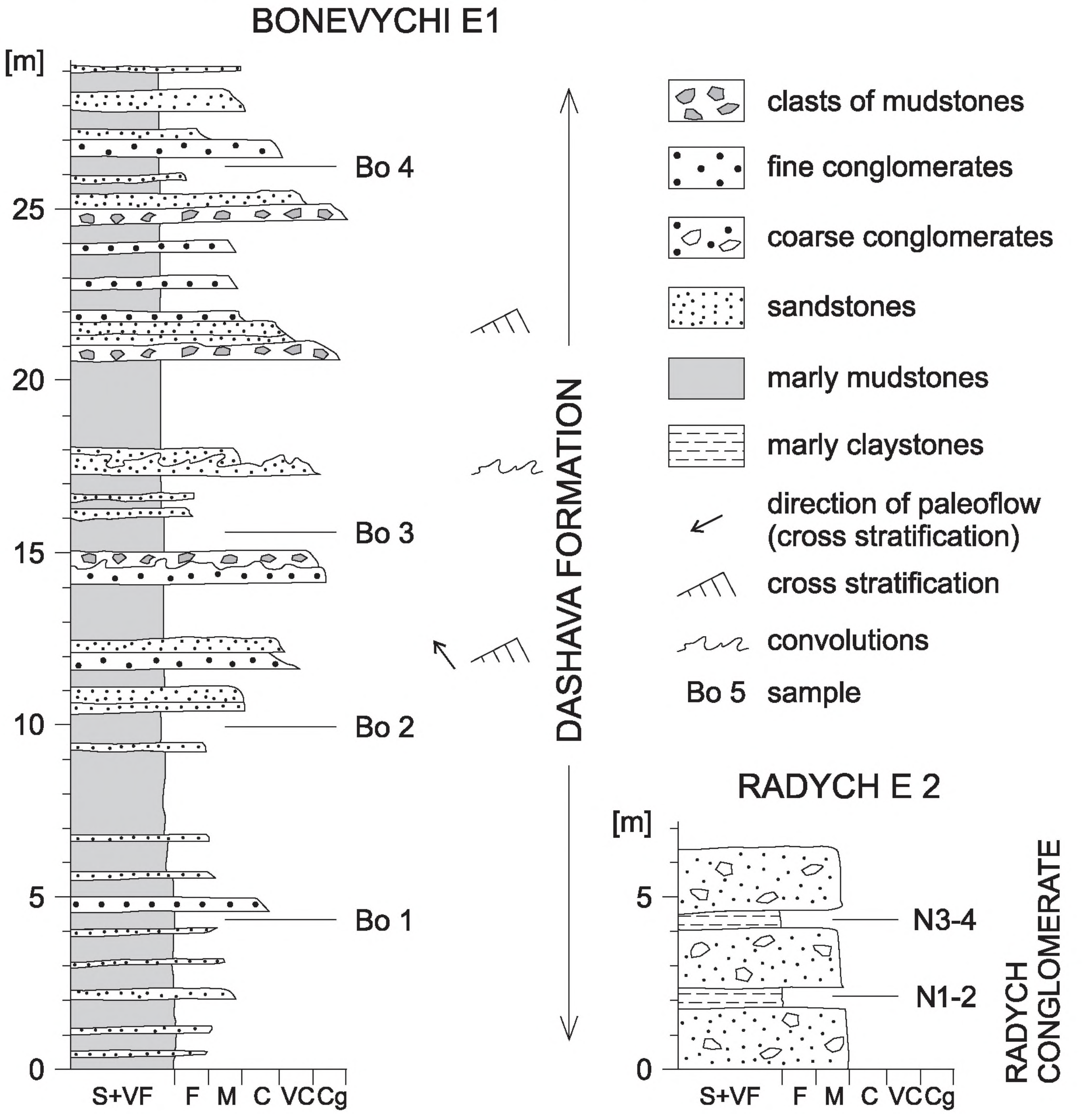

Fig. 14. Lithostratigraphic logs of the Bonevychi and Radych sections

Discoaster druggii Assemblage Zone (NN2)

AGE: Early Miocene; upper Egerian and lower Eggenburgian stages of Central Paratethys (= upper Aquitainian and lower Burdigalian Stage, MSS 2004).

REMARKS: This zone was identified in the upper part of the Menilite Beds and in the lower part of the Polyanytsia Formation exposed in the Prut River near the town of Delatyn (Text-fig. 4, Table 2; samples D1-D3 and DX),

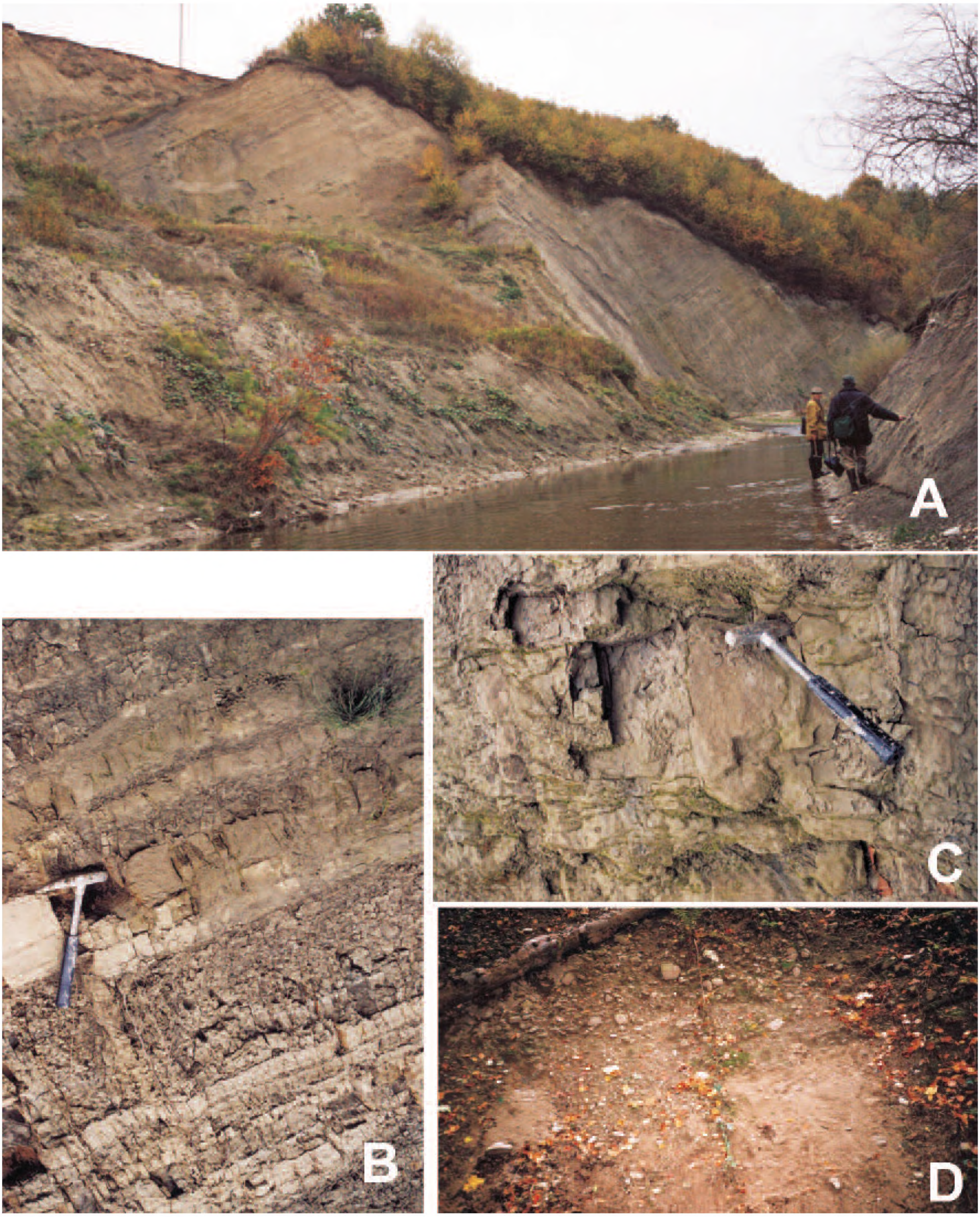

Fig. 15. A – General view of the exposures of the Dashava Formation along the Vyrva River at Bonevychi; B – Thin-bedded turbidites of the Dashava Formation. Vyrva River exposures at Bonevychi; C – Thick-bedded, poorly cemented sandstones with load cast at the base; D – Radych poorly cemented conglomerates. Radych Hill near Dobromil

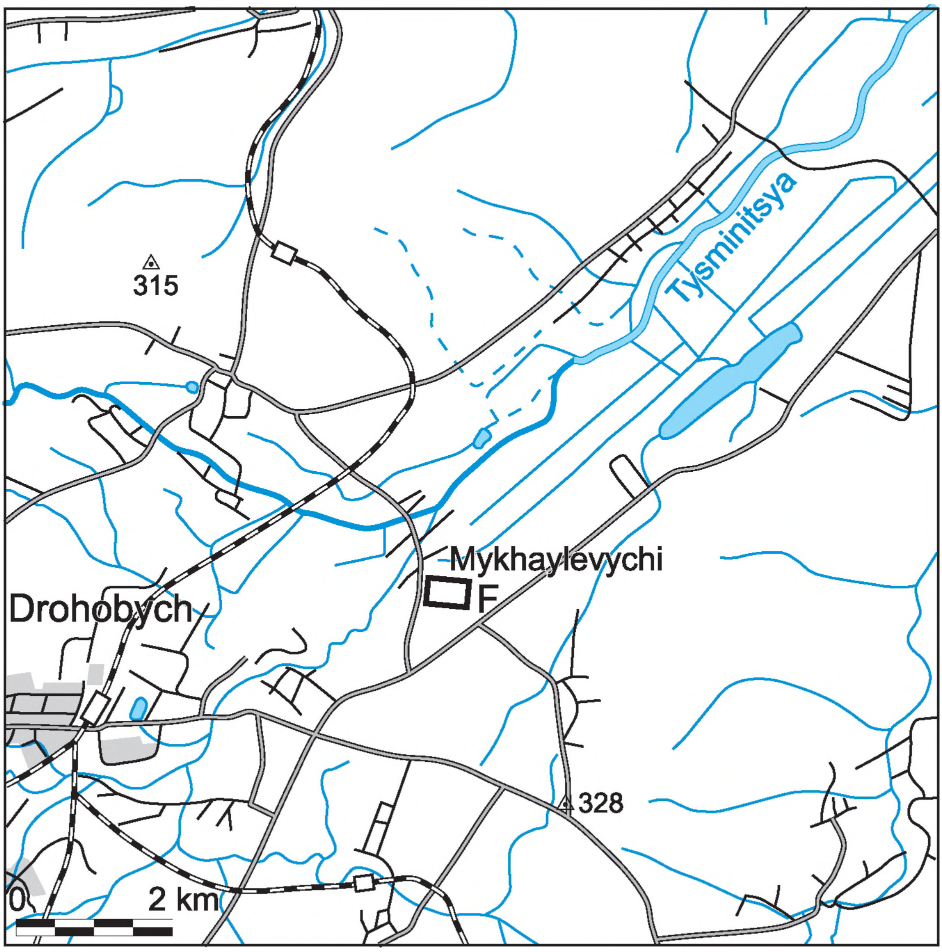

Fig. 16. Sketch-map of the Mykhailovychi area near Drohobych

The zone is defined by the following species: *Discoaster druggii* BRAMLETTE & WILCOXON, *Sphenolithus conicus* BUKRY, *Sphenolithus disbelemnos* FORNACIARI & RIO, *Reticulofenestra pseudoumbilica* (GARTNER) (small), and *Triquetrorhabdulus carinatus* MARTINI. According to the standard zonation of MARTINI (1971) and MARTINI & WORSLEY (1970), *R. pseudoumbilica* first appears in the NN5 Zone. MARUNTEANU (1999), however, reported this species from as low as the basal NN2 Zone. According to YOUNG (in BOWN 1998), the first accurence (FO) of *S. disbelemnos* and/or *Umbilicosphaera rotula* (KAMPTNER) is a reliable biostratigraphical marker just above the lower boundary of the NN2 Zone.

Besides the listed species, the typical association of this zone is represented by: *Coccolithus pelagicus* (WALLICH), *Cyclicargolithus floridanus* (ROTH & HAY), *Helicosphaera ampliaperta* BRAMLETTE & WILCOXON, *H. carteri* (WALLICH), *H. granulata* (BUKRY & PERCIVAL), *H. intermedia* MARTINI, *Orthorhabdulus serratus* BRAMLETTE & WILCOXON, *Reticulofenestra* sp. (small), *Sphenolithus dissimilis* BUKRY & PERCIVAL, *S. moriformis* (BRONNIMANN & STRADNER), *Thoracosphaera heimi* (LOHMANN), *Triquetrorhabdulus challengeri* PERCH-NIELSEN.

Sphenolithus belemnos Assemblage Zone (NN3) and probably lowermost *Helicosphaera ampliaperta* Zone (NN4)

AGE: Early Miocene; upper Eggenburgian and lower Ottnangian stages of the Central Parathethys (= upper Burdigalian Stage, MSS 2004).

REMARKS: These zones were found in the Vorotyscha Formation (Text-fig. 4, Table 2, sample D4) as exposed in the Prut River near the villages of Delatyn (Zarichye section) and Lanchyn (Lanchyn section). The typical association of this interval is represented by: *Calcidiscus leptoporus* (MURRAY & BLACKMAN), *Coccolithus pelagicus, Cyclicargolithus floridanus, Discoaster adamanteus* BRAMLETTE & WILCOXON, *D.*

deflandrei BRAMLETTE & RIEDEL, *D. druggii*, *Helicosphaera ampliaperta*, *H. carteri*, *H. euphratis* HAQ, *H. granulata*, *H. intermedia*, *H. mediterranea* MŰLLER, *H. scissura* MILLER, *Orthorhabdus serratus*, *Pontosphaera multipora* (KAMPTNER), *Reticulofenestra minuta* ROTH, *R. pseudoumbilicus*, *Sphenolithus belem-*

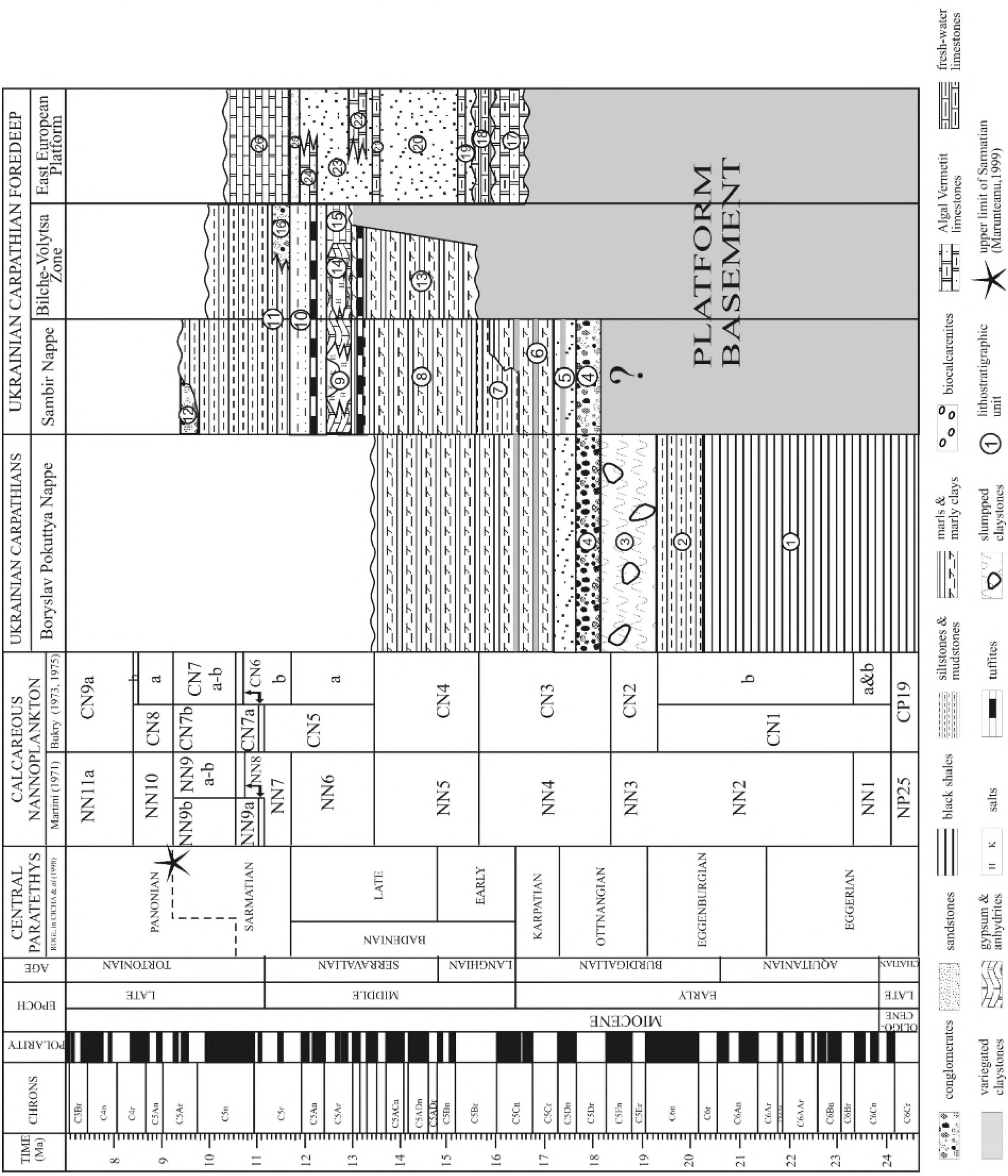

Table 1. Regional stratigraphic scheme of the Miocene deposits of the Ukrainian Carpathian Foredeep (after OSZCZYPKO & *al* 2006, supplemented). The Miocene time scale after BERGGREN & *al.* (1995) and RÖGL in CICHA & *al.* (1998); Lithostratigraphic units: 1 – Upper Menillite Beds, 2 – Polanytsya Formation, 3 – Vorotyshcha Formation, 4 – Sloboda Conglomerate, 5 – Dobrotiv Formation, 6 – Stebnyk Formation, 7 – Balych Formation, 8 – Bohorodchany Formation, 9 – Kalush (Tyras) Formation, 10 – Kosiv Formation, 11 – Dashava Formation, 12 – Radych beds, 13 – Zhuriv Formation, 14 – Tyras Formation, 15 – Ratyn limestones, 16 – Pistyn conglomerates, 17 – Nahoryany (Oncophora) beds, 18 – Berezhany beds, 19 – Baraniv beds, 20 – Mykolaiv beds, 21 – Naraiv beds, 22 – Rostoche and Kaiserwald beds, 23 – Kryvchytsi beds, 24 – Ternopil beds, 25 – Buhliv beds, 26 – Volyn beds

nos BRAMLETTE & WILCOXON, *S. disbelemnos*, *S. dissimilis*, *S. moriformis*, *Thoracosphaera heimi* and *Triquetrorhabdulus milowii* BUKRY.

Helicosphaera ampliaperta Assemblage Zone (NN4)

AGE: Early Miocene; Karpatian and lower Badenian stages of Central Paratethys (= uppermost Burdigalian and lower Langhian stages, MSS 2004).

REMARKS: This zone was identified in the Stebnyk Formation exposed in the Prut River near Lanchyn (Lanchyn section, Text-fig. 7, Table 2, samples L1-L5). The zonal assignment is based on the co-occurrence of the following species: *Sphenolithus heteromorphus* DEFLANDRE, *Calcidiscus premacintyrei* THEODORIDIS and *Helicosphaera ampliaperta.* The FO of *Sphenolithus heteromorphus* is usually found close to the last occurrence of *Sphenolithus belemnos* (zonal marker for the lower boundary of the NN4 Zone) and thus can be used to approximate the NN3 and NN4 boundary (see YOUNG, 1998). According to the standard zonation of MARTINI (1971) and MARTINI and WORSLEY (1970), the last occurrence of *Helicosphaera ampliaperta* is at the top of NN4. The samples also contain *Calcidiscus premacintyrei.* The first occurrences of these species are in the lower part of zone NN4.

The typical association of this zone is represented by: *Calcidiscus premacintyrei*, *C. tropicus* (KAMPTNER), *Coccolithus miopelagicus*, *C. pelagicus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *D. variabilis* MARTINI & BRAMLETTE, *Helicosphaera ampliaperta*, *H. carteri*, *H. euphratis*, *H. granulata*, *H. intermedia*, *H. mediterranea*, *H. scissura*, *Orthorhabdus serratus*, *Pontosphaera multipora*, *Reticulofenestra daviesii* (HAQ), *R. haqii* BACKMAN, *R. minuta*, *R. pseudoumbilica*, *Sphenolithus heteromorphus*, *S. moriformis* and *Triquetrorhabdulus milowii*.

Middle Miocene

Sphenolithus heteromorphus Assemblage Zone (NN5)

AGE: Middle Miocene; lower Badenian Stage of Central Paratethys (= upper Langhian Stage, MSS 2004).

REMARKS: This zone was identified in the Stebnyk Formation, exposed in the Prut River at Lanchyn (Lanchyn section, Text-fig. 7, Table 2, sample L8)

The zonal assemblage is composed of: *Sphenolithus heteromorphus, Calcidiscus premacintyrei, Helicosphaera waltrans* THEODORIDIS and *H. walbersdorfensis* MÜLLER. The FOs of the two latter species are widely accepted as a good marker for the base of the zone (FORNACIARI & *al.* 1996; YOUNG 1998). However, according to ŠVÁBENICKÁ (2002), the stratigraphic range of *H. waltrans* corresponds to the range of *Globigerinoides bisphericus* and *H. waltrans* should thus appear already in the upper NN4 Zone. This author (ŠVÁBENICKÁ 2002; TOMANOVA-PETROVA & ŠVÁBENICKÁ 2007) suggested a diachronous appearance of the species, with earlier occurrences in the Paratethys. An important feature is the continuous range of *S. heteromorphus* and *C. premacintyrei* following the disappearance of *Helicosphaera ampliaperta.* Besides the forms listed, the typical association of this zone is composed of: *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *Coccolithus pelagicus*, *Coronocyclus nitescens* (KAMPTNER), *Cyclicargolithus floridanus*, *Discoaster exilis* MARTINI & BRAMLETTE, *D.* sp. (5 rays), *Helicosphaera carteri*, *H. intermedia*, *Orthorhabdus serratus*, *Pontosphaera multipora*, *Reticulofenestra pseudoumbilicus*, *R. minuta*, *R.* sp. (small), *Sphenolithus moriformis*, *Thoracosphaera heimii*, *Triquetrorhabdulus milowii*, *T.* sp. and *Umbilicosphaera rotula.*

Assemblage zones NN6-NN7?

AGE: Middle Miocene, upper Badenian (Central Paratethys) and Serravalian stages, MSS 2004.

REMARKS: These zones were found in the upper part of the Kalush Formation and documented in the Petranka area (Text-fig. 11, Table 2, samples P1, P2, P4, P5, P7, P9, P12). The typical association is represented by: *Calcidiscus leptoporus*, *C. macintyrei* (>10 μm), *C. premacintyrei*, *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Coronocyclus nitescens*, *Discoaster exilis*, *D. variabilis*, *Helicosphaera carteri, H. walbersdorfensis*, *Pontosphaera multipora*, *Reticulofenestra pseudoumbilicus* (>7 μm), *R. minuta*, *Sphenolithus abies*, *Syracosphaera pulchra* LOHMANN, *Triquetrorhabdulus rioi* OLAFSSON, *T. rugosus* and *Umbilicosphaera rotula*.

Upper Miocene

Catinaster coalitus Assemblage Zone (NN 8)

AGE: Late Miocene; lower Tortonian Stage.

REMARKS: This zone was identified in the Sand-Clays Formation exposed in the Vyrwa River in the villages of Bonevychi and Mykhailevychi (Text-fig. 14, Table 3, samples Bo1-Bo4). The base of the zone is defined by the FO of *Catinaster coalitus* MARTINI & BRAMLETTE.

sample loccality	DELATYN					LANCHYN										PETRANKA						
sample number	D1	D2	D3	DX	D4	L1	L2	L3	L4	L5	L6	L7	L8	L11	L13	P1	P2	P5	P4	P7	P9	P12
lithostratigraphy	upper Menilite Fm			PF	VF	Stebnyk Fm												Kosiv Fm	Kalush Fm			
Baarudosphaera bigelowii		x																				
Calcidiscus leptoporus				x	x	x		x	x		x	x	x	x	x	x	x	x	x	x	x	x
Calcidiscus macintyrei																x		x	x	x		x
Calcidiscus premacintyrei									x									x			x	
Calcidiscus sp.							x															
Calcidiscus tropicus													x									
Calciosolenia murrayi													x									
Coccolithus miopelagicus									x				x	x	x	x	x					x
Coccolithus pelagicus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Coronocyclus nitescens (elliptical)																				x	x	
Cyclicargolithus abisectus	x	x	x	x	x																	
Cyclicargolithus floridanus	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x
Discoaster adamanteus					x																	
Discoaster cf. *variabilis*													x				x					
Discoaster cf.*drugii*		x																				
Discoaster deflandrei				x	x				x				x									
Discoaster druggii				x	x																	
Discoaster exilis								x														
Discoaster sp.								x				x				x	x	x	x	x	x	x
Discoaster variabilis													x								x	
Helicosphaera Intermedia					x				x		x		x	x		x		x				
Helicosphaera wallichii																						
Helicosphaera ampliaperta			x		x				x		x		x	x								
Helicosphaera carteri					x			x	x		x		x	x	x	x	x	x	x	x	x	x
Helicosphaera cf. *stalis*																		x				
Helicosphaera cf. *Intermedia*			x																			
Helicosphaera cf.*ampliaperta*	x							x														
Helicosphaera cf.*granulata*		x	x																			
Helicosphaera euphratis					x				x				x									
Helicosphaera granulata					x				x		x		x			x						
Helicosphaera mediterranea					x				x				x	x								
Helicosphaera scissura					x				x				x	x								
Helicosphaera sp.					x		x	x	x		x	x	x			x						
Helicosphaera vedderi														x								
Helicosphaera walbersdorfensis											x		x			x	x	x		x	x	
Helicosphaera waltrans													x									
Holodiscolihus macroporus													x									
Orthorhabdus serratus				x	x								x	x		x						
Pontosphaera multipora					x			x	x		x	x	x	x	x	x	x	x	x	x	x	x
Pontosphaera sp.					x		x															
Reticulofenestra daviesii													x	x								
Reticulofenestra haqii													x									
Reticulofenestra minuta					x		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Reticulofenestra pseudoumbilicus					x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Reticulofenestra sp.*small*	x	x	x																			
Rhabdosphaera sp.													x									
Sphenolithus abies																x	x	x		x	x	x
Sphenolithus belemnos					x																	
Sphenolithus disbelemnos					x									x								
Sphenolithus dissimilis	x	x	x	x	x									x								
Sphenolithus heteromorphus													x									
Sphenolithus moriformis		x	x		x								x	x	x	x						
Sphenolitus sp.					x		x															
Syracosphaera pulchra																	x	x		x	x	x
Thoracosphaera heimii				x	x			x	x		x	x	x	x	x	x	x	x				
Thoracosphaera sp.					x		x					x										
Triquetrorhabdulus carinatus		x																				
Triquetrorhabdulus challengeri	x	x																				
Triquetrorhabdulus milowii				x	x			x	x		x	x	x	x	x	x		x				
Triquetrorhabdulus rugosus																x	x	x		x	x	x
Triquetrorhabdulus sp.	x		x	x	x		x		x		x		x	x	x							
Triquetrorhabdulus sp.					x			x	x													
Umbilicosphaera cf. *rotula*								x						x	x	x	x	x	x	x	x	x

Table 2. Calcareous nannofossil distribution in the Delatyn, Lanchyn and Petranka sections

Catinaster calyculus MARTINI & BRAMLETTE also appears in this zone. OKADA & BUKRY (1980) used this event to subdivide their CN7 Zone and define the lower limit of their CN7b Zone. The typical association of this zone is composed of: *Calcidiscus leptoporus*, *C. macintyrei* (>10 µm), *Catinaster calyculus*, *C. coalitus*, *C. mexicanus* BUKRY, *Coccolithus pelagicus*, *Discoaster bellus* BUKRY & PERCIVAL, *D. quinqueramus* GARTNER, *D. variabilis*, *Discoaster* sp. (5 rays.), *Helicosphaera carteri*, *H. intermedia*, *H. stalis* THEODORIDIS, *Pontosphaera multipora*, *Reticulofenestra pseudoumbilica* (>7 µm), *R. minuta*, *Sphenolithus abies* DEFLANDRE, *Scyphosphaera lagena* (KAMPTNER), *S. apsteinii* LOHMANN, *Syracosphaera pulchra*, *Thoracosphaera heimii*, *Triquetrorhabdulus rugosus*, *Umbilicosphaera jafari* MÜLLER, and *U. rotula*.

Discoaster hamatus Assemblage Zone (NN9)

AGE: Late Miocene; lower Tortonian Stage (marine analogue of the Pannonian Stage from the Central Paratethys).

REMARKS: This zone was identified in the Sand-Clays Formation exposed in the road-cut in the Mikhaylevychi section (Text-fig. 16, Table 3, samples M1-M4) and in the Radych Conglomerate exposed in the Radych section (Text-fig. 14, Table 3, samples N1-N3)

The zone is defined by the following assemblage: *Catinaster calyculus*, *Catinaster coalitus*, *Discoaster hamatus* MARTINI & BRAMLETTE, and *Discoaster prepentaradiatus* BUKRY & PERCIVAL. The FO of *D. hamatus* defines the base of this zone. In the middle of the

sample loccality	BONEVYCHI				NOVE MISTO			MYKHAYLEVYCHI			
sample number	B1	B2	B3	B4	N 1	N 2	N 3	M 1	M 2	M 3	M 4
lithostratigraphy	Dashava Fm				Radych Conglomerates			Dashava Fm			
Calcidiscus leptoporus	x	x	x	x	x	x		x	x	x	x
Calcidiscus macintyrei	x	x			x	x		x	x	x	x
Catinaster calyculus					x	x				x	x
Catinaster coalitus	x	x			x	x					
Catinaster mexicanus								x			
Catinaster sp.	x										
Coccolithus pelagicus	x	x	x	x	x	x	x	x	x	x	x
Cyclicargolithus floridanus	x	x									
Discoaster adamanteus	x										
Discoaster aff. *berggrenii*								x			
Discoaster bellus								x			x
Discoaster cf. *pentaradiatus*						x					
Discoaster cf. *variabilis*								x			
Discoaster cf.*quingueramus?*								x			
Discoaster hamatus					x	x			x		
Discoaster kugleri	x				x			x		x	
Helicosphaera wallichii	x	x			x	x				x	x
Helicosphaera ampliaperta											
Helicosphaera carteri	x	x	x	x	x	x		x	x	x	x
Helicosphaera cf. *intermedia*								x			
Helicosphaera sellii						x					
Helicosphaera stalis					x	x		x			
Pontosphaera multipora	x	x	x	x	x	x		x	x	x	x
Reticulofenestra minuta	x	x			x	x		x		x	x
Reticulofenestra pseudoumbilicus	x	x	x	x	x	x	x	x	x	x	x
Scyphosphaera apshtenii	x										
Scyphosphaera lagena		x									
Sphenolithus abies	x	x	x		x	x		x	x	x	x
Syracosphaera pulchra	x	x	x	x	x	x		x	x	x	x
Thoracosphaera heimii	x	x	x	x	x	x		x	x	x	x
Triquetrorhabdulus rugosus	x	x			x	x		x	x	x	x
Umbilicosphaera cf. *rotula*	x	x	x	x	x	x		x	x	x	x
Umbilicosphaera jafari	X	x	x		x	x		x	x	x	x

Table 3. Calcareous nannofossil distribution in the Bonevychi, Nove Misto and Mykhaylevychi sections

zone *D. prepentaradiatus* (BUKRY & PERCIVAL, 1971) appears. The other characteristic species of the zone are: *Calcidiscus leptoporus, C. macintyrei* (>10 µm), *Coccolithus pelagicus, Helicosphaera carteri, H. stalis, H. wallichii, Pontosphaera multipora, Reticulofenestra pseudoumbilica* (>7 µm), *R. minuta, Sphenolithus abies, Syracosphaera pulchra, Thoracosphaera heimii, Triquetrorhabdulus rugosus, Umbilicosphaera rotula* and *U. jafari*.

REMARKS ON PALAEOECOLOGY BASED ON THE OCCURRENCES OF THE NANNOFLORAS

The productivity and distribution of the nannofloras in the studied Miocene deposits were controlled by palaeogeographic condition related to late Alpine tectonics. In effect, several small, partly separated basins, with abundant terrigenous material in the surface water were created. This condition was unfavourable for the productivity of Haptophyte algae.

The species diversity of the nannoflora in the Miocene basins of the Northern and Eastern Carpathians was similar to that in the Mediterranean area; however, the flora was much less abundant. In the Outer Carpathians the marine and saline basins existed throughout the Miocene although the latter were characteristic of the Carpathian foredeep. The saline basins were characterised by low-abundance nannofloral associations with a high content of redeposited specimens, often up to 90-95% in a nannoplankton assemblage.

The Miocene nannoplankton associations in the sections studied indicate warm water basins with unstable hydrodynamic and salinity conditions, and with a high influx of terrigenous material.

FORAMINIFERAL BIOSTRATIGRAPHY

Foraminiferal associations were generally scanty and only in a few samples were rich enough to determine their age:

1. Zarichye Section, Upper Menilite Beds: Sample D2 yielded a Miocene association with *Cibicides* aff. *boryslavensis* (AISENSTAD), *C. refulgens* MONFORT, and abundant smaller *Cibicides* and reworked older species *Globotruncana* sp. and *Heterohelix globulosa* EHRENBERG. Sample D1 contained long-ranging species: *Grammostomum* sp., *Rhabdammina* sp. and *Subbotina* sp. Samples D3-D5 were barren.
2. Oslava Section, Sloboda Conglomerate: Two samples yielded Early Miocene association composed of: *Ammodiscus incertus* D'ORBIGNY, *Chiloguembelina* sp., *Glomospira charoides* (PARK & JONES), *Rhabdammina* sp. and small *Globigerina* sp.
3. Petranka village, Sections P1 and P2: Samples P1-P3 yielded mixed Paleogene and Neogene material, represented by small and broken specimens. Sample P4 yielded a Miocene association composed of *Globigerina* aff. *falkonensis* BLOW, *G. praebulloides* BLOW, and *Praeglobobulimina pupoides* (D'ORBIGNY).
4. Uhryniv Section: Sample P5 contained a mixed assemblage composed of Paleogene [*Acarinina primitiva* (FINLAY), *Subbotina linaperta* (FINLAY)] and Miocene species [two specimens of *Ammonia beccarii* (LINNÉ) and a single specimen of *Cibicides* ex gr. *ungerianus* D'ORBIGNY]. Samples P6-P11 were barren.
5. Bonevychi Section: Samples Bo1-Bo4 provided a uniform Middle Miocene assemblage with *Ammonia* cf. *beccarii* LINNÉ, *Asterigerinata planorbis* (D'ORBIGNY), *Globigerina bulloides* D'ORBIGNY, *Globigerina praebulloides* BLOW, *Hanzawaia boueana* (D'ORBIGNY) and *Uvigerina pygmoides* (PAPP & TURNOVSKY).
6. Radych Section: Sample N1 contained a Middle Miocene association with *Ammonia beccarii tepida* D'ORBIGNY, *Caucasina gutsulica* (LIVEROVSKA), *Gyroidina marina* PISHVANOVA, together with the Eocene *Subbotina corpulenta* SUBBOTINA, and the Cretaceous *Globotruncana arca* (CUSHMAN) and *Pseudotextularia varians* (RZEHAK). Sample N2 yielded a Miocene association with *Ammodiscus* cf. *miocenicus* KARRER, *Cassigerinella* cf. *globulosa* (EGGER), *Cibicides boryslavensis* (AISENSTAD) and *Globigerinella obesa* (BOLLI). Sample N3 contained long-ranging species: *Repmanina charoides* (JONES & PARK) and *Rhizammina* sp.
7. Mykhaylevychi Section. Sample M1 contained five specimens of *Hyperammina* sp. and sample M2 contained small Miocene species: *Brzalina* ex gr. *dilatata* REUSS, *Cassigerinella* sp., *Chiloguembelina cubensis* (PALMER), *Globigerina postcretacea* MJATLUK and *Planorotalia* sp.

DISCUSSION

Our litho- and biostratigraphic studies show that the folded Miocene deposits of the lower Boryslav-Pokuttya Nappe represent the terminal flysch deposits, while the upper portion of this nappe and the Sambir Nappe represent the molasse deposits. Stratigraphically these deposits range from the early to the late Miocene. The terminal flysch deposits are represented by the Upper Menilite and Polyanytsya formations (NN2 Zone). The Vorotyshcha salt-bearing Formation (NN3-NN4 Zones) records the transition from the flysch to molasse deposits, although in the inner part of the Skyba/Skole Nappe the flysch-type sedimentation persisted longer than in the marginal part of the Carpathians, up to the ?Karpatian (ŚLĘZAK & *al.* 1995).The molasse deposition begins with the Sloboda Conglomerate, dated as Ottnangian/Karpatian. These coarse clastic rocks are rich in the platform pre-Cambrian slates and schists as well as the Mesozoic (Jurassic) limestones. They contain only scarce Miocene foraminifera. Eastwards of Delatyn, the Sloboda Conglomerate overlaps the Boryslav-Pokuttya Nappe, which was already folded and partly eroded (GLUSHKO 1976). This implies that, during the Karpatian, when flysch-like sedimentation still continued in the inner part of the Skyba/Skole basin, part of the Boryslav Pokuttya zone started to be folded, uplifted and eroded.

In the sections studied, the Sloboda Conglomerate passes up into the Dobrotiv and Stebnyk formations. These Karpatian-Early Badenian strata display a fining- and thinning- upwards megasequence, capped by the Late Badenian salts.

The Stebnyk and Balych formations should be regarded as more or less isochronous (Karpatian/ Badenian) lithofacies which record the transition from terrestrial to shallow-marine environments. The Stebnyk (red) lithofacies occupied the south-eastern part of the sedimentary area (Text-fig. 7), and the Balych lithofacies is typical of its north-eastern part. Sections in the Petranka area display an interfingering of these two lithofacies (Text-fig. 11).

The salt deposits in Wieliczka and Bochnia in Poland are dated as Late Badenian, and are isochronous with the salt deposits in the Kalush areas in Ukraine. These deposits contain thick complexes of redeposited, brecciated salts (see ANDREYEVA-GRIGOROVICH & *al.* 2003). Pelitic intercalations within these salt deposits contain calcareous nannoplankton assemblages corresponding to the NN6 Zone and to the undivided interval referred to zones NN6–NN7. A Late Badenian age is also indicated by the foraminifera. The sub-evaporitic beds in the Wieliczka Salt Mine (the uppermost part of the Skawina Formation) belong to the transition zone between the NN5 and NN6 zones and, in the case of the Bochnia Salt Mine and the Kalush 340 borehole succession (see Text-fig. 2), to a lower part of the NN6 Zone. It implies that the lower boundary of salt deposition could have been diachronous. Sediments overlying the salt sequence (Chodenice beds in Poland and the lower Kosiv beds in Ukraine) belong to the NN6/NN7 zones interval (Late Badenian/Early Sarmatian). Connection between salt basins in front of the Ukrainian and Polish Carpathians is still disputable as there is a lack of salt deposits in the north-west part of the Sambir Nappe, near the Polish border. The cross-sections through the Wieliczka, Bochnia and Kalush salt mines suggest that the halite subbasins were relatively narrow and separated by the sulphate subbasins (see Text-fig. 2). Salt deposition probably took place in en echelon subbasins?.

In the Salt Breccia Member in the Wieliczka Salt Mine Sarmatian-type foraminifera occur that are unknown from the Ukrainian salt deposits. This can be explained by redeposition of salt deposits by gravitational flow at the end of the Badenian and/or at the boundary between the Badenian and Sarmatian. It can also be explained by local development of brackish environments in the marginal part of the basin, caused by an influx of fluvial waters from the nearby Carpathian Range. The importance of inflow of fluvial waters to the salt basin has already been pointed out by BUKOWSKI & *al.* (2001). It should be mentioned that the earlier studies (ŁUCZKOWSKA & ROLEWICZ 1990) demonstrated the existence of foraminiferal assemblages that were not younger than Badenian, and that the calcareous nannoplankton was only of Late Badenian age. In the Sambir succession, the Kalush or Tiras formations pass up into clayey-sandy deposits of the Kosiv and Dashava formations. The upper part of the Dashava Formation (Bonevychi and Mykhaylevychi sections) contains Late Sarmation calcareous nannofossils. This formation is overlapped by the Radych flysch-derived conglomerates, which record the youngest stage of Sambir subbasin development at the front of the overriding Eastern flysch Carpathians. The same age of the youngest deposits of the Romanian Carpathian Foredeep was documented by MARUNTEANU (1999) and MARUNTEANU & *al.* (1999).

To the west, in the Przemyśl area, the Sambir Nappe continues into the Stebnik Nappe of the eastern part of the Polish Outer Carpathians. The Stebnik Nappe has been recognised in front of and beneath the Skole Nappe, south-east of Przemyśl (NEY 1968). In the Stebnik Nappe the Lower Miocene deposits are represented by coarse-grained clastic deposits. Their relationship to the platform or flysch basement is not clear. In Poland, these sediments (NEY 1968, OSZCZYPKO & *al.* 2006) comprise two informal subdivisions: the Vorotyshcha and Stebnik formations (GARECKA & OLSZEWSKA 1997). The Vorotyshcha Formation in Poland (up to 300 m thick) represents probably only the upper part of this subdivision (NEY 1968). These beds are composed of grey, marly claystones with dispersed gypsum and salt. The uppermost part of this formation contains at least 200 m of conglomerates. The planktonic foraminifera from the Vorotyshcha Formation comprise poorly diversified, long-ranging species. The calcareous nannoplankton assemblage is represented by: *Helicosphaera ampliaperta, H. walbersdorfensis, Reticulofenestra pseudoumbilicus* and *Sphenolithus heteromorphus*, and belongs to the Ottnangian-Karpatian (NN3-NN4 zones, see GARECKA & OLSZEWSKA 1997, 1998). The Stebnyk Formation is characterised by the appearance of rose-coloured and dark grey calcareous mudstones with intercalations of thick-bedded sandstones in the lower part of the formation. The calcareous nannoplankton of the Stebnyk Formation contains higher numbers of reworked Paleogene and Cretaceous specimens, accompanied by sparse Miocene species: *Discoaster* cf. *variabilis, Helicosphaera walbersdorfensis, H.* cf. *californiana* and *Sphenolithus heteromorphus* which suggest the top of the NN4 Zone (GARECKA & OLSZEWSKA 1997, 1998). According to GARECKA & OLSZEWSKA (1998) the deposition of the Stebnyk Formation crossed the Karpatian/Badenian boundary. The Stebnyk Formation is overlain by the Balych Formation, up to 1000 metres thick, which is represented by grey and greenish-grey calcareous clays with intercalations of sands and sandstones. The calcareous nannoplankton assemblage indicates the NN4 Zone (Ottnangian – Lower Badenian), but in some localities the early Badenian species *Praeorbulina glomerosa* and *Orbulina universa* and calcareous nannoplankton of the NN5 Zone have been discovered (GARECKA & OLSZEWSKA 1997, GARECKA & JUGOWIEC 1999). The Balych Formation passes up into greenish-grey mudstones and poorly cemented sandstones and conglomerates of the Lower Badenian Przemyśl Beds (NEY 1968), with intercalations of gypsum and anhydrites at the top. The youngest deposits of the Stebnyk succession consist of marly mudstones with intercalations of tuffites (Pikulice Beds – Upper Badenian); and the Radych Conglomerate, the muddy matrix of which sometimes contains Early Sarmatian foraminifera of the *Anomalinoides dividens* Zone (OLSZEWSKA 1999).

Between Przemyśl and Kraków, along the Carpathian frontal thrust, there is a narrow zone (up to 10 km) of folded Badenian and Sarmatian deposits. The western part of this zone was distinguished as the Wieliczka-Bochnia Folds (Badenian Folds, see KSIĄŻKIEWICZ 1977). Subsequently, KOTLARCZYK (1985) distinguished all the folded Badenian and Sarmatian deposits in front of the Polish Carpathians as the Zgłobice Thrust-sheets. A recent new interpretation of the geology of the Zgłobice area (Wojnicz and Biadoliny slices) as a triangle zone was given by KRZYWIEC *& al.* (2004), whereas the Dębno slice (KRZYWIEC *& al.* 2004), is probably a prolongation of the Wieliczka–Bochnia Folds.

The biostratigraphic data presented in this paper clearly support an earlier suggestion (ANDREYEVA-GRIGOROVICH & *al.* 2003) that, although the Carpathian Foreland Basin went through three main environmental stages during the Badenian (open marine, hypersaline and open marine), the previous subdivision of the Badenian into three parts (Lower, Middle and Upper) is difficult to accept. The previous Middle Badenian (Wielician; ŁUCZKOWSKA 1978) Substage corresponds to the NN6 and NN6/7 zones and is therefore largely of Late Badenian age. The foraminifera from the salt complexes are also typical of the Late Badenian.

The new biostratigraphic results also have important tectonic implications. The Sambir Nappe is flatly overthrust onto the Dashava Formation (Sarmatian) of the outer Carpathian Foredeep (Bilche–Volytsia Zone), whereas the youngest deposits of the Sambir Nappe (Dashava Formation) are of Late Sarmatian–Early Tortonian age. It means that the Sambir Nappe was finally folded and thrust during post-Sarmatian time. In the Polish sector of the Carpathian Foredeep, the Sambir (Stebnyk) Nappe and the Badenian-Sarmatian slices in front of the Carpathians are thrust onto Late Badenian–? Sarmatian deposits. The youngest deposits of the folded Miocene Zone in Poland are in general classified as Late Badenian–Sarmatian, while the Late Sarmatian deposits are known only from the Andrychów area (WÓJCIK & JUGOWIEC 1998).

It is now possible to state that both the Sambir (Stebnyk) Nappe and the Zgłobice thrust-sheets were finally folded during post-Sarmatian time. In the Sambir Nappe the folding and thrusting embraced both the Early, Middle (Badenian and Sarmatian) and Late Miocene (Tortonian). The folded Miocene strata represent continuous tectonic units that run in front of the Carpathians. The disappearance of the Lower Miocene within the folded zone towards the west could be an effect of the flatter surface of the Carpathians overthrust and/or the shallow location of the European Platform basement.

KRZYWIEC & *al.* (2004), based on seismic profiles, proposed a new interpretation of the Zgłobice thrust sheets in their typical development (Brzesko-Wojnicz area in Poland). According to this paper "the central part of the Zgłobice Unit is interpreted as a passive-roof duplex defining a Miocene triangle zone". The frontal part of the duplex is backthrust by synform fill with Chodenice and Grabowiec beds (Upper Badenian –? Lower Sarmatian). In this interpretation, the triangle zone is a syndepositional structure. It means that the "triangle zone" records the initial stage of compression, before the main episode of thrusting and tectonic transport of the Sambir Nappe and its western prolongation, the Wieliczka-Bochnia Folds.

CONCLUSIONS

1. The field observations clearly show the vertical transition from the Sloboda Conglomerates to the Dobrotiv and Stebnyk formations. This fining- and thinning-upwards sequence records the transition from the Late Burdigalian terrestrial and fresh-water deposition to the Langhian regional marine transgression.
2. The analysis of exotic material within the Truskavets and Sloboda conglomerates, represented by metamorphic rocks and Palaeozoic and Mesozoic limestones, together with Menilite-type black shales, suggests that the Late Burdigalian Boryslav–Pokuttya and Sambir basin was supplied both from the uplifted part of the East European Platform as well as from the Carpathian orogen.
3. The strong folding of the Stebnik and Balych formations suggests that the exceptional thicknesses of these formations encountered in deep boreholes is an effect of tectonic repetition.
4. The higher part of the Stebnik lithofacies passes into the Balych lithofacies, as already suggested by BUJALSKI (1930). They represent the highest part of the Karpatian and lower part of the Badenian. This type of lithofacies is developed in the north-west part of the Sambir Nappe, between Dolyna and Dobromil.
5. Evaporitic deposits in the Sambir Nappe, near the Polish border, disappear locally and pass into marly-sandy deposits.
6. Part of the grey-coloured deposits in the north-west part of the Sambir Nappe, regarded hitherto as the Balych Formation, actually represents the Sarmatian Dashava Formation, as shown, for example, in exposures along the Vyrva River and in the Mykhaylevychi area near Drohobych.
7. In the time when part of the Boryslav-Pokuttya zone was already folded and eroded and invaded by shallow water molasse sedimentation in the inner area of the Skyba/Skole basin marine flysch sedimentation still continued.
8. The Sambir Nappe was finally folded and thrust during post-Sarmatian time.

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PLATE 1

Early Miocene calcareous nannofossils

1, 2 – *Catinaster* sp.; sample B1.
3-5 – *Catinaster calyculus* MARTINI & BRAMLETTE,1963; sample M3.
6, 7 – *Catinaster coalitus* MARTINI & BRAMLETTE,1963; sample B1.
8 – *Discoaster adamanteus* BRAMLETTE & WILCOXON, 1967; sample B1. (redeposited)
9 – *Discoaster* aff. *berggrenii* BUKRY, 1971b; sample M1.
10 – *Discoaster kugleri* MARTINI & BRAMLETTE,1963; sample B1.
11 – *Discoaster* cf. *pentaradiatus* TAN, 1927; sample NM2.
12, 13 – *Discoaster hamatus* MARTINI & BRAMLETTE,1963; sample M2.
14 – *Helicosphaera stalis* THEODORIDIS, 1984; sample M1.
15 – *Helicosphaera stalis* THEODORIDIS, 1984; sample NM2.
16, 17 – *Reticulofenestra pseudoumbilica* (>7 µm) (GARTNER, 1967), GARTNER,1969; sample M4.
18 – *Sphenolithus abies* DEFLANDRE,1954; sample M1.
19, 20 – *Triquetrorhabdulus rugosus* BRAMLETTE & WILCOXON, 1967; sample M3.

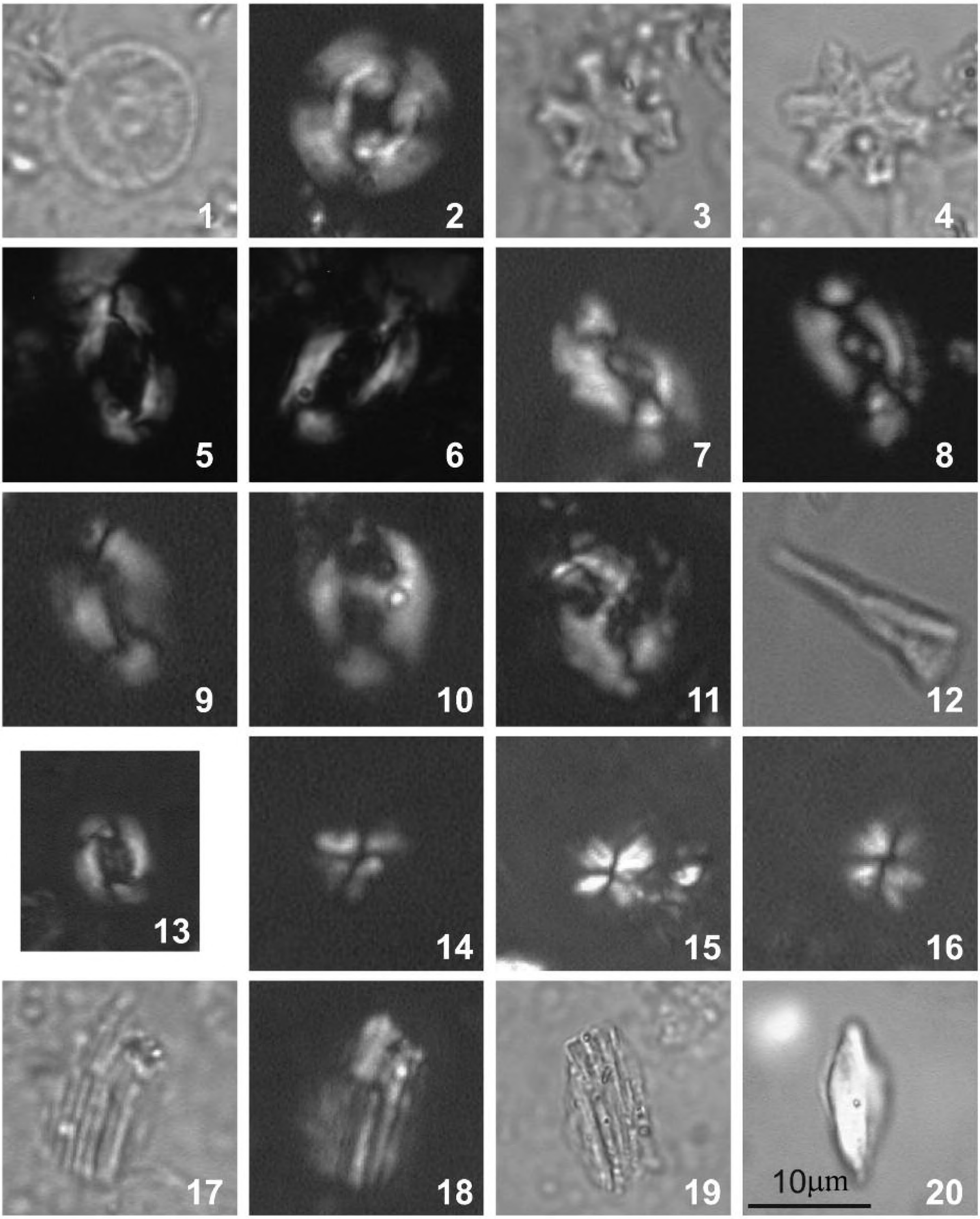
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PLATE 2

Middle Miocene calcareous nannofossils

1, 2 – *Calcidiscus macintyrei* (>11µm) (BUKRY & BRAMLETTE, 1969) LOEBLICH & TAPPAN, 1978; sample P1.
3 – *Calcidiscus premacintyrei* THEODORIDIS, 1984; sample P5.
4 – *Calciosolenia murrayi* GRAN, 1912; sample L8.
5 – *Coccolithus miopelagicus* BUKRY, 1971; sample P12.
6 – *Coronocyclus nitescens* (KAMPTNER, 1963) BRAMLETTE & WILCOXON, 1967; sample P7.
7, 8 – *Discoaster exilis* MARTINI & BRAMLETTE, 1963; sample L3.
9 – *Discoaster variabilis* MARTINI & BRAMLETTE, 1963; sample L8.
10 – *Helicosphaera carteri* (WALLICH, 1877) KAMPTNER, 1954; sample L8.
11, 12 – *Helicosphaera walbersdorfensis* MÜLLER, 1974; sample L8.
13, 14 – *Helicosphaera waltrans* THEODORIDIS, 1984; sample L8.
15 – *Holodiscolihus macroporus* (DEFLANDRE, 1954) ROTH, 1970; sample L8.
16 – *Reticulofenestra pseudoumbilica* >7 µm (GARTNER, 1967), GARTNER, 1969; sample L8.
17 – *Rhabdosphaera* sp.; sample L8.
18 – *Sphenolithus heteromorphus* DEFLANDRE, 1953; sample L8.

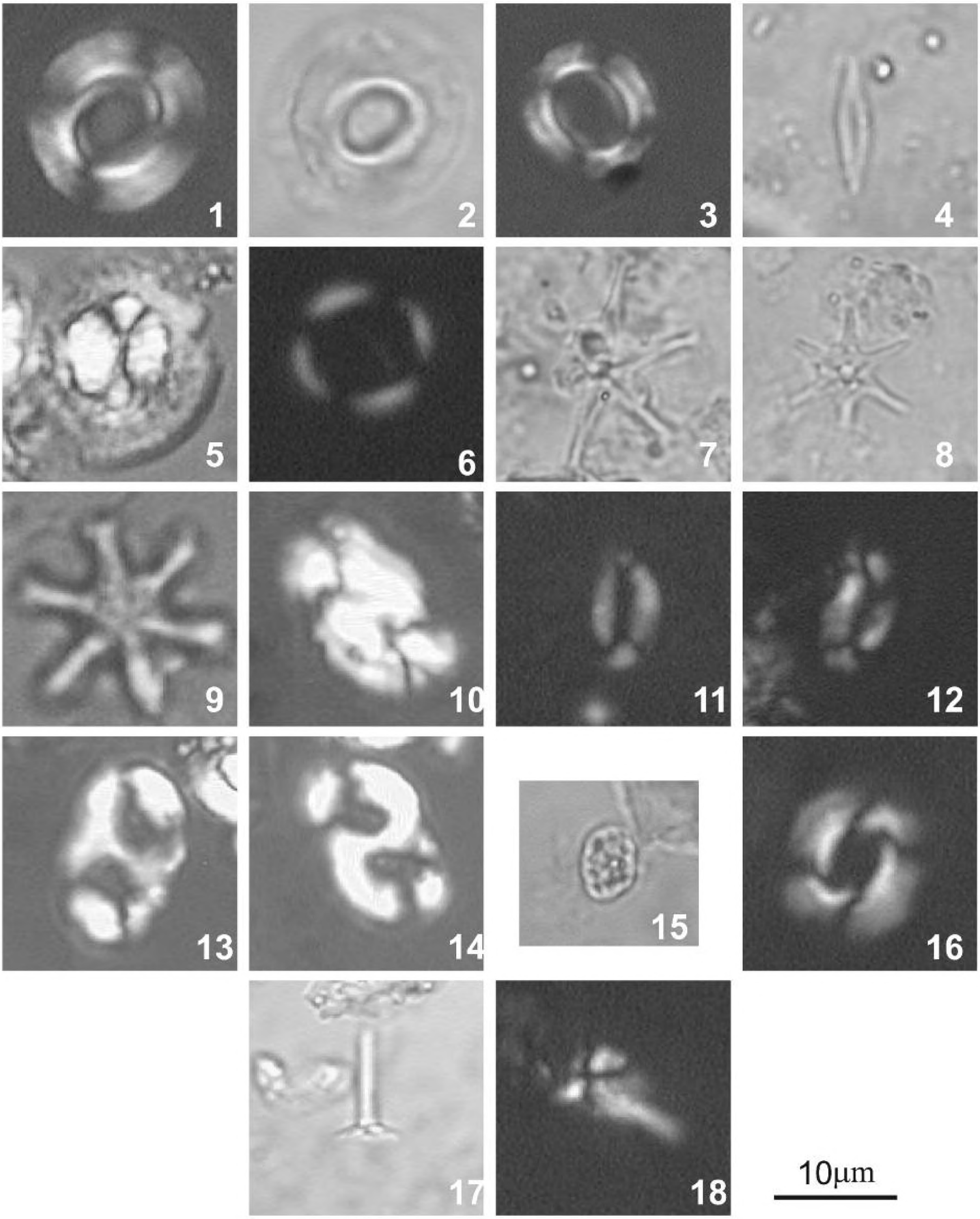
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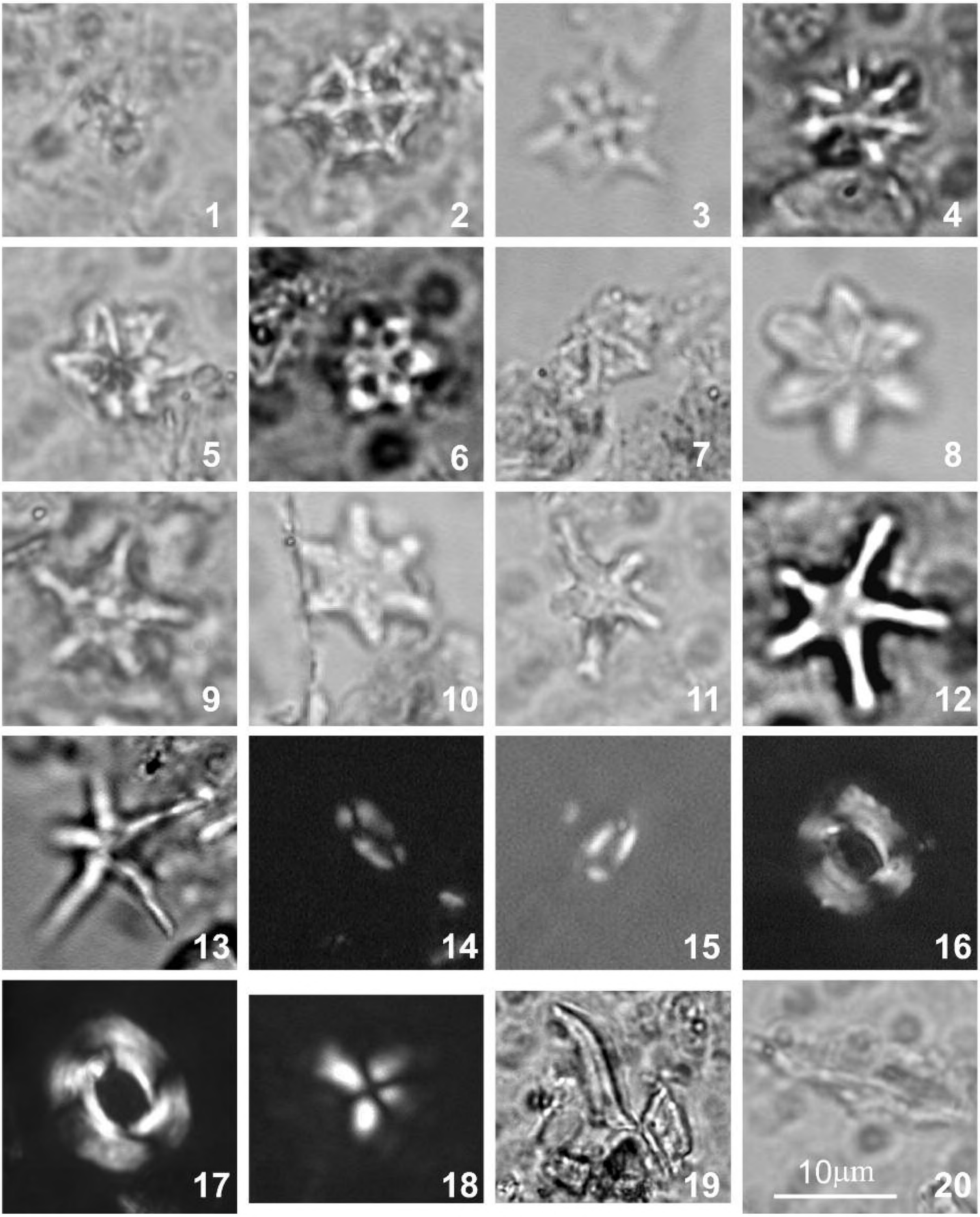
PLATE 3

Late Miocene calcareous nannofossils

1 – *Calcidiscus leptoporus* (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978; sample D4.
2 – *Cyclicargolithus abisectus* (MÜLLER, 1970) WISE, 1973; sample D1.
3 – *Discoaster deflandrei* BRAMLETTE & RIEDEL, 1954; sample DX.
4 – *Discoaster druggii* BRAMLETTE & WILCOXON, 1967; sample DX.
5, 6 – *Helicosphaera ampliaperta* BRAMLETTE & WILCOXON, 1967; sample D3.
7, 8 – *Helicosphaera intermedia* MARTINI, 1965; sample D4.
9 – *Helicosphaera scissura* MILLER; sample D4.
10, 11 – *Helicosphaera mediterranea* MÜLLER,1981; sample D4.
12 – *Orthorhabdus serratus* BRAMLETTE & WILCOXON, 1967; sample DX.
13 – *Reticulofenestra daviesii* (HAG, 1968) HAG, 1971; sample L8.
14 – *Sphenolithus disbelemnos* FORNACIARI & RIO, 1996; sample D4.
15, 16 – *Sphenolithus dissimilis* BUKRY & PERCIVAL, 1971; sample D1.
17-19 – *Triquetrorhabdulus challengeri* PERCH-NIELSEN, 1977; sample D2.
20 – *Triquetrorhabdulus milowii* BUKRY, 1971; sample DX.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